Pollen Dispersal Across the Southern Alps, South Island, New Zealand

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To my parents.

ABSTRACT

The aim of this research was to improve the understanding of modern pollen deposition in central South Island in order to interpret Quaternary pollen profiles. This was accomplished by examining the results from a chain of pollen traps (exposed for one year), moss polsters collected along a transect from Westland across the Southern Alps to Canterbury (with and without addition of exotic spores to facilitate 'absolute' counting) and three short peat monoliths. The role of topography, vegetation type and weather patterns were also briefly assessed. The results were analysed by means of principal components and cluster analyses to identify the respective contribution of different pollen taxa. The conclusions are: 1. Trap and polster results are broadly comparable. 2. With exceptions, caused by local effects such as fire and contributions by adjacent vegetation and taxa introduced since 1850, the monolith profiles show little change over the period studied. 3. Forest sites in Westland were dominated by pollen of local podocarps (*Dacrydium cupressinum*, *Prumnopitys*) and broadleaved angiosperm species (*Metrosideros*, *Quintinia*, *Weinmannia*). *Nothofagus fusca* type pollen dominates within the beech forest areas, but drops to about 10% a short distance from the forest edge. Poaceae pollen shows low frequencies in forested sites, but dominates in grass/scrubland areas. 4. Sites above the treeline on the Main Divide shows proportionately high counts of exogenous Podocarpaceae pollen. However, the high counts involve no 'real' increase in regional deposition.

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CHAPTER 1

1.1 INTRODUCTION

To correctly interpret pollen diagrams from peat or other sediment profiles for the reconstruction of past environments, it is essential to have a sound knowledge of the relationship between pollen and spore deposition and the vegetation from which the palynomorphs originated.

The methods most commonly used to record modern pollen deposition include:

1. Collection of moss polsters and analysis of the palynomorphs therein.
2. Collection of the upper layers of lake sediments and their analysis.
3. Some form of pollen trap exposed to receive the fallout of palynomorphs from the atmosphere.

Lewis and Ogden (1965) discuss the various methods of collecting pollen in these ways, their advantages and disadvantages. Moss polsters are believed to yield pollen spectra representative of the pollen deposition over the last few years. There is less control over the period of accumulation for lake sediments (Lewis and Ogden 1965). Pollen traps collect pollen over a known period of time and (if the trap functions well), show the accumulation of each taxa precisely. The results of the moss polster or surface lake sediments analysis are less precise, but nevertheless probably approximate past conditions of deposition, as reflected in peat profiles, averaged over periods of a decade or so. The problem with pollen trapping is that long runs of years are needed to smooth out the year to year vagaries of pollen production, weather patterns, etc.

A summary of pollen deposition studies in New Zealand up to 1981 is outlined by Pocknall (1982). Most such work in this country has attempted to discover information about relative dispersal and proportionate representation of pollen of the main taxa present in Quaternary sites. However, some (including recent studies initiated by Dr. D. Fountain of Massey University) has been directed towards understanding the relationship between pollen deposition and human allergies (Clark 1951; Licitis 1953). Prior to the work of Moar (1970, 1971), Pocknall (1978, 1980, 1982) and McGlone (1982), pollen analysts in New Zealand lacked detailed information on the relationship between modern pollen deposition and vegetation. The use of surface samples in New Zealand has provided a qualitative description of the vegetation surrounding the sampling sites (Moar 1970, 1971). These studies emphasised the difference in pollen dispersal between wind and insect-pollinated species. A

pollen trapping programme in central Canterbury, showed that *Nothofagus* is always an important component (Myers 1973) (important in the context of the super abundance of *Nothofagus* in many pollen spectra).

Several studies have related modern pollen deposition to a quantitative description of vegetation (Pocknall 1978, 1980, 1982). Pocknall showed that the modern pollen deposition at sampling sites is not necessarily proportional to the abundance of the source taxa in the vegetation. McGlone (1982), using surface samples in Egmont National Park, characterised a forest vegetation type lacking *Nothofagus* in terms of its pollen spectra.

There is still a general lack of detailed information in New Zealand, regarding the relationship between modern pollen deposition and the vegetation from which the pollen originated. There is little or no information on the variability of pollen spectra on local sites due to topography and about the effects of wind and precipitation patterns and distance from the pollen sources.

1.2 AIM OF RESEARCH

The aim of this research is to amplify information about the modern pollen deposition in order to assist in the interpretation of Quaternary pollen diagrams.

This will be achieved by:

1. Determining how much pollen is deposited on a seasonal and yearly basis.

2. Examining the relationship between plant communities and their pollen assemblages. The emphasis is on a comparative approach (Birks and Birks 1980) attempting to identify plant communities in terms of their pollen assemblages and to discover the nature of the contribution of different source areas to the pollen assemblages across a transect.

3. Examining the immediate past history of pollen deposition at three locations.

The aim will be accomplished by examining the results from pollen traps, surface samples (moss polsters) along a transect and three shallow peat profiles. These studies are to be done in conjunction with assessment of the role of topographic, vegetation and weather patterns in the dispersal and deposition of pollen.

CHAPTER 2

STUDY AREA AND SITE LOCATION

2.1 INTRODUCTION

Terrain relief interacts with wind flow to determine the actual precipitation pattern. Wind and rain in turn affect the dispersal of pollen and spores. Pollen and spore deposition is also affected by vegetation and other surface features, with contrasts, for example, between the patterns to be expected in a forested location compared with grassland. This chapter describes the general topography, patterns of precipitation and vegetation distribution in the study area. The location and a brief description of the terrain and vegetation at each of the sampling sites are given.

2.2 THE STUDY AREA

2.2.1 Terrain

The South Island of New Zealand lies between latitudes 40° 30'S. and 47° 02'S. The Southern Alps, which lie along a southwest to northeast axis divide the island into western and eastern portions. The study area extends on a transect from the coast into the Taramakau catchment in central Westland, across the Main Divide of the Southern Alps at Arthur's Pass into the Waimakariri catchment and through the Canterbury Ranges to the Canterbury Plains. The general topography of the study area and the location of the sampling sites are shown in Figure 2.1. Table 2.1 provides detailed location data and general categories for the sites used in this study.

Elevations along the transect range from 100 m in Westland, 930 m at Arthur's Pass (with surrounding peaks Mt Rolleston 2270 m and Mt Temple 1893 m), 550 m at Cass (surrounding peaks: Sugar Loaf 1360 m, Mt Horrible 1204 m, Mt Misery 1760 m) and 930 m at Porters Pass (surrounding peaks 1733 m).

The narrow Westland lowlands are formed from dissected moraines and outwash plains and river flood plains. To the east, mountains rise abruptly to 1370-1650 m asl.

Near the Main Divide, with its jagged, glaciated peaks, the valleys are narrow, deep-cut and steep-walled. Valley sides seldom rise at an angle of less than 25-30 degrees (Figure 2.2). Similar terrain occurs just east of the Main Divide but the valley floors are higher than those in Westland.

Table 2.1 Location of the 43 surface samples on a transect from the West Coast of central Westland to Porters Pass in Canterbury.

Site	Location	Grid Ref.	Altitude (metres)	Sample Type	General description of site
A1	West Coast	654725	3	Moss	Sand dunes near pastures
A2	West Coast	654725	3	Lichen	Sand dunes near pastures
B	Kumara	706648	120	Moss	Scrub and grassland
C	Loop Line Road	764547	165	Moss	Podocarp/broadleaf forest
D	Wainihinihi	847505	90	Lichen	Grassland/scrubland
E	Taipo River	926522	120	Lichen	Pasture near podocarp/broadleaf forest.
F	Jacksons	005525	180	Moss	Grassland/scrubland
G	Aickens	098470	455	Moss	Grassland near podocarp/broadleaf forest
H	Barrack Creek	056394	520	Moss	Opening in podocarp/broadleaf forest
I	Otira Gorge	054392	520	Moss	Scrub/grassland near podocarp/broadleaf forest
J	Rolleston River	043381	520	Moss	Scrub/grassland near podocarp/broadleaf forest
K	Lower Bog Main Divide	052327	925	Moss	Subalpine scrub, grassland and herbfield
L	Upper Bog Main Divide	053326	930	Moss	Subalpine scrub, grassland and herbfield
M	Dobson Memorial	054323	930	Moss	Subalpine scrub, grassland and herbfield
N	Bealey River	050303	825	Moss	Mountain beech forest
O	Quarry Knob Bog	088217	730	Moss	Mountain beech forest
P	Quarry Knob	090216	740	Moss	Mountain beech forest
Q	Quarry Bog	093214	730	Moss	Mountain beech forest
R	Bealey Forest	123158	975	Moss	Mountain beech forest
S	Woolshed Hill Bog	230235	1055	Moss	Mountain beech forest
T	Lower Woolshed Bog	223234	670	Moss	Mountain beech forest
U	Horrible Bog (N)	205190	640	Moss	Open marshy area in scrubland/grassland
V	Horrible Bog	205184	640	Moss	Open marshy area in scrubland/grassland
W	Waterfall Terrace	208172	640	Moss	Grassland/scrubland
X	Cass	230171	550	Moss	Grassland/scrubland
Y	Misery Swamp	208162	610	Moss	Grassland/scrubland
Z	Lake Sarah	244157	580	Moss	Swamp on lake margin in grassland/scrubland
AA	S.E. Lake Sarah	251146	580	Moss	Grassland/scrubland
AB	Kettlehole Bog	254147	610	Moss	Grassland/scrubland
AC	Waimakariri	271147	485	Moss	Grassland/scrubland
AD	St Bernard Saddle	264137	610	Moss	Grassland/scrubland
AE	Ribbonwood Stream	244115	580	Moss	Grassland
AF	Lake Hawdon	308091	580	Moss	Swamp on lake margin in grassland/scrubland
AG	Lake Hawdon Bog	311090	580	Moss	Grassland/scrubland
AH	Slovens Stream (N)	328051	550	Moss	Grassland/scrubland
AI	Vagabonds Inn	319038	610	Moss	Grassland
AJ	Slovens Stream	329032	550	Moss	Grassland/scrubland
AK	Craigieburn Cutting	213028	915	Moss	Scrubland
AL	Cave Stream	207022	790	Moss	Grassland/scrubland
AM	Castle Hill	205959	700	Moss	Grassland/scrubland
AN	Willow Tree Bog	185881	825	Moss	Small mire in grassland/scrubland
AO	Starvation Gully	207853	915	Moss	Scrubland/Grassland
AP	Porters Pass	216851	930	Moss	Scrubland/Grassland

Maps used:

Sites A-E	NZMS 1 S50 & 51 Hokitika	1:63350 4th Edition 1978
Sites F	NZMS 1 S52 Harper Pass	1:63350 2nd Edition 1977
Sites G-Q,S,T	NZMS 1 S59 Otira	1:63350 4th Edition 1985
Sites R,U-AM	NZMS 1 S66 Broken River	1:63350 3rd Edition 1980
Sites AN-AP	NZMS 1 S74 Springfield	1:63350 6th Edition 1986

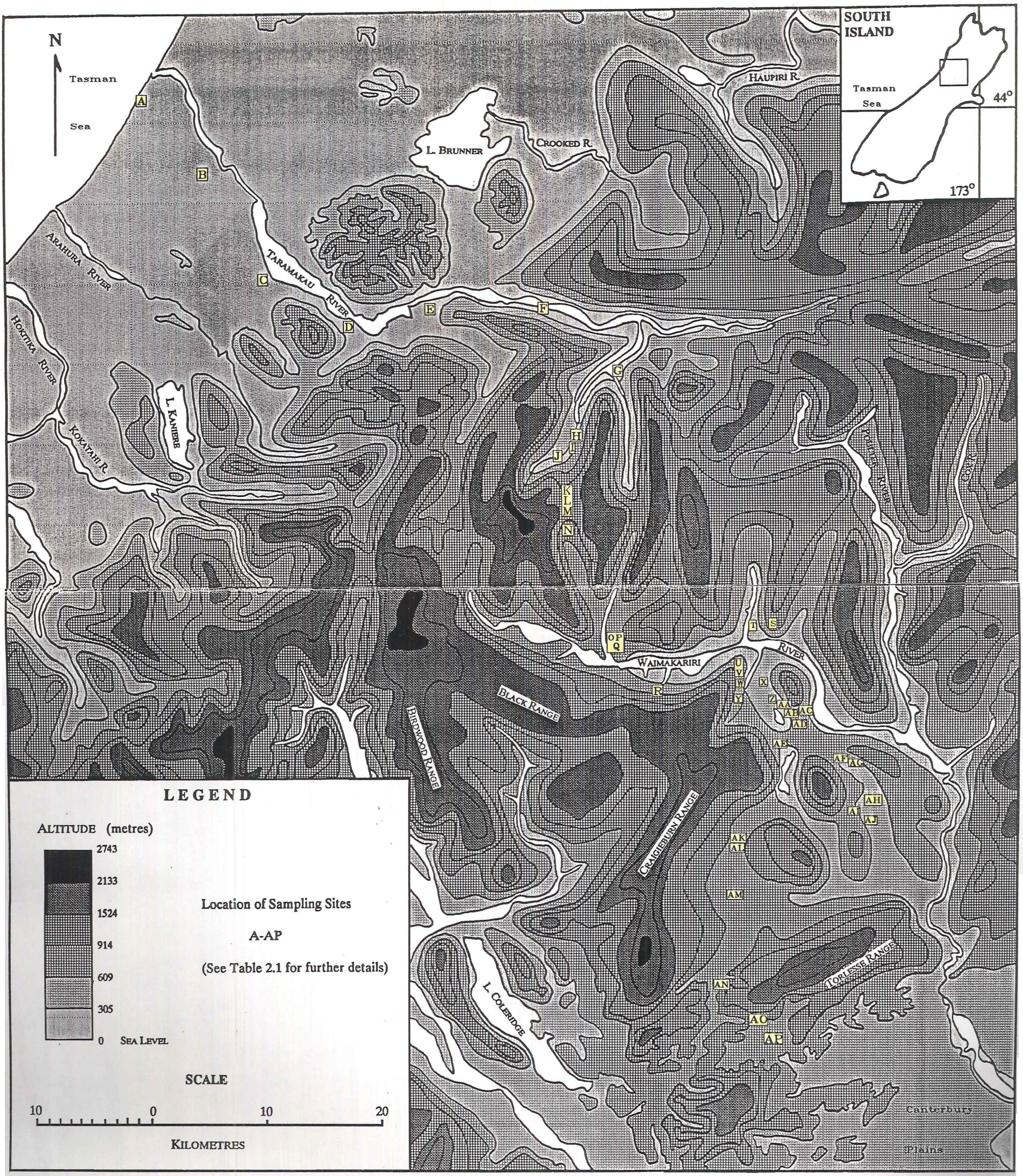


Figure 2.1 General topography of the study area showing the location of the sampling sites.

Figure 2.2 Looking from the top of the Otira Gorge to the west. Note the steep slopes clad with broadleaved angiosperm trees. In the foreground is subalpine scrub.

Figure 2.3 A panoramic view from Sugar Loaf looking south-west along the Waimakariri River. Note the wide valley, morainic ridges, and flat river flood plain

The Cass Basin is bounded by scree-clad mountains with rounded summit profiles. The wide valley has a relatively flat floor with morainic ridges, low hills, alluvial fans and flat river flood plains (Figure 2.3). Similar terrain extends eastward to Porters Pass, before the descent to the Canterbury Plains.

2.2.2 Meteorology.

The weather patterns in the study area are the result of three dominant controlling influences: 1. Oceanic position of New Zealand; 2. characteristics of the atmospheric circulation due to migratory anticyclones in the mid-latitude Southern Hemisphere, and the orientation of the low-pressure troughs between them; and 3. the area's structure and surface configuration.

The high rainfall in Westland is caused by unstable, warm, moist, air masses from the west, rising as they pass onto the high steep-sided Southern Alps. However, central Westland though affected by frequent cloud and rain, is also a relatively sunny place. The average number of hours of sunshine per annum for Hokitika is 1883 ($\pm$126) and that for Christchurch is 1985 ($\pm$103) (Coulter 1978). The mountains of the Main Divide have a dramatic effect on rainfall patterns. Frequently when rain is falling on the Main Divide, Cass, 20 kilometres east, will be fine (Figure 2.4). When the westerly airstream reaches the Torlesse Range, it is often dry, strong and gusty (Molloy 1963).

The other major wind direction which affects the study area, is from the south-west. South-westerly changes can occur quite suddenly and are responsible for considerable falls of snow to low levels in winter (Morris 1965). These changes can also bring snow to the mountains in other seasons (Figure 2.5).

The precipitation pattern in the study area is shown in Figure 2.6. The rainfall gradient across the transect is variable. The average rainfall at Kumara on the west coast of Westland is 2800 mm, 5600 mm at Otira, at the base of the Southern Alps; 6400 mm on the the Main Divide at Arthur's Pass, declining to 4000 mm at Arthur's Pass Village. At Bealey it is 1600 mm, at Cass 1300 mm and at Porters Pass 1100 mm (NZMS 19).

The study area is windy. However, strong winds are normally confined to exposed mountain tops and some eastern valley sites. Surface winds below 10000 ft (ca. 3000 m) (Gabites 1953) are strongly affected by the orientation of the mountain ranges. The prevailing westerly winds blow down the valleys and through gaps, varying greatly in strength and direction (Garnier 1958) (Figure 2.7). The maximum westerly flow at low levels is in late spring.

Figure 2.4 The Southern Alps covered in cloud, while at Cass the weather is fine.

Figure 2.5 Looking west at the Torlesse Range with fresh snow. Photograph taken 24 December 1989.

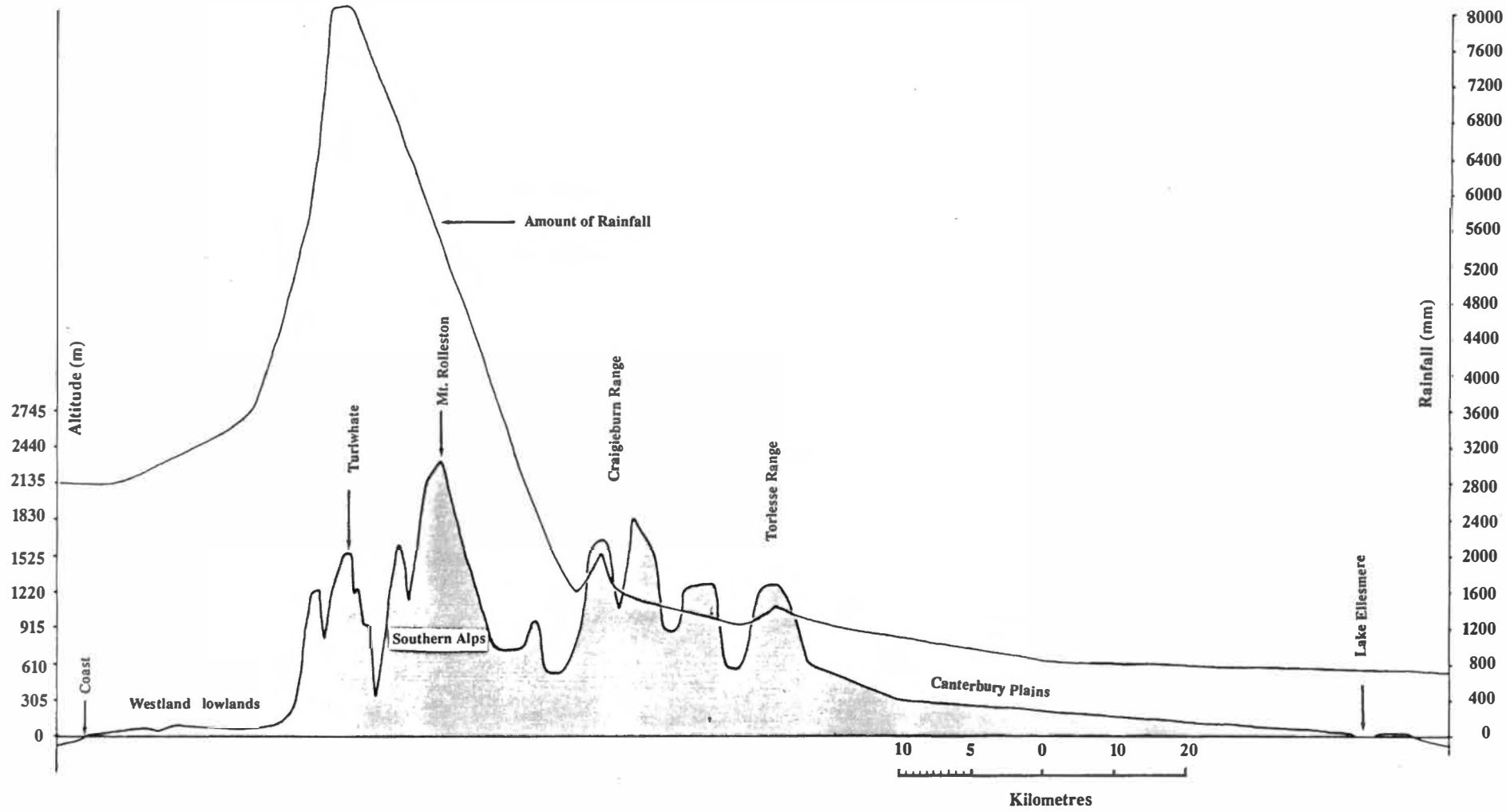


Figure 2.6 Cross-section across the South Island illustrating the relationship between relief and rainfall in the study area. (Rainfall data from New Zealand Map Series 19, Sheet 5, Christchurch, Rainfall Normals 1941-70.

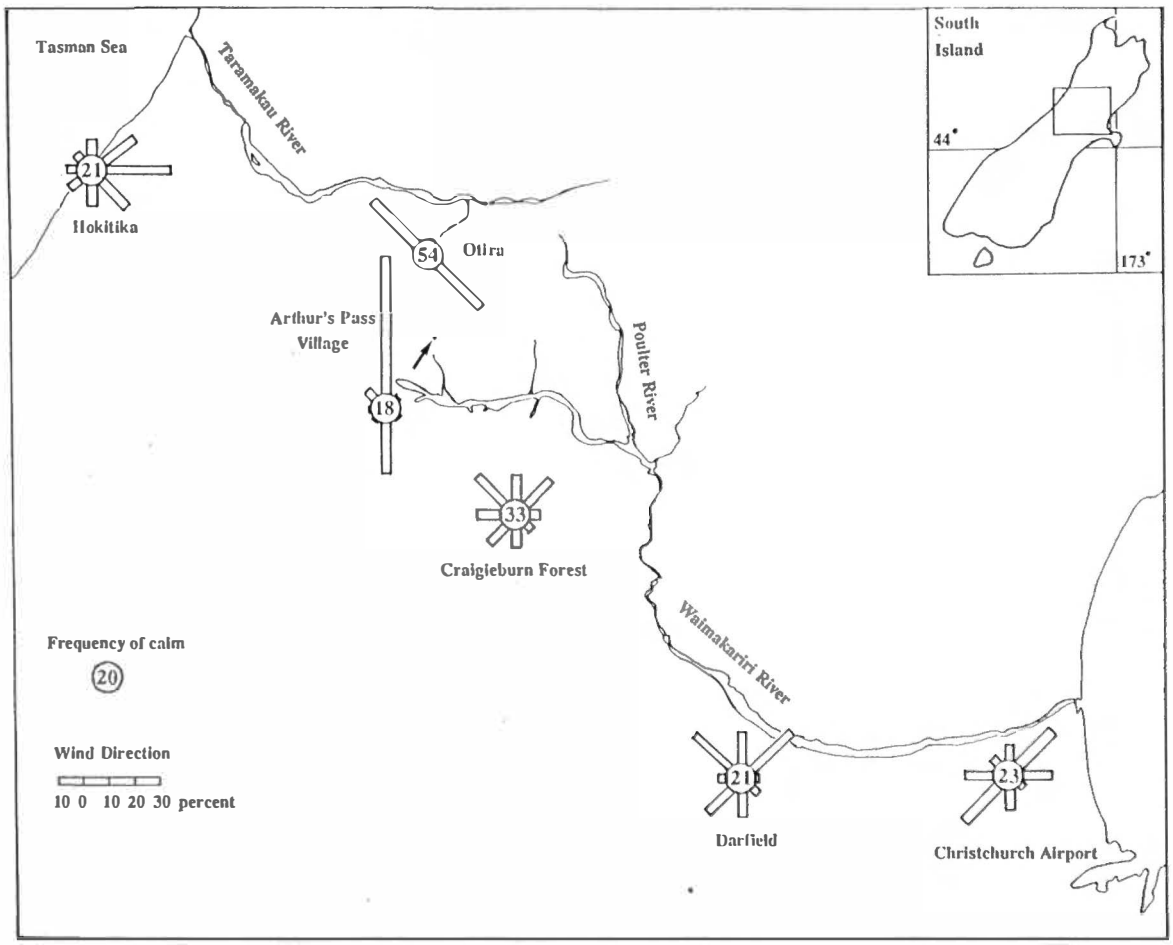


Figure 2.7 Mean annual percentage frequency of surface wind direction (at 0900 NZST) in the study area. (NZ Met. Svc. Misc. Pub. 149, 1983-86).

2.2.3 Vegetation

There have been several vegetation studies in the area. Some of the more recent are: Reif and Allen (1988) describing the 43 community types in central Westland including species composition of the main canopy, understorey and ground cover; McKelvey (1984) main canopy species in Westland forests; Burrows (1986) (a checklist of the vascular flora of Arthur's Pass National Park); and Wardle (1970 a,b,c,d) defines 23 associations for *Nothofagus solandri* throughout New Zealand of which nine types occur in the study area. Other references (e.g. Burrows 1962, 1977a,b) merely classify the vegetation into forest, scrub and grassland.

Much of this information is uneven. The majority of the data in Masters *et al.* (1957); McKelvey (1984) and the NZFS maps are biased towards economically important forest trees. Only some of the data are expressed as abundances and no data are available on quantity of shrubs and herbs in the study area. For this reason, no attempt could be made to determine a percentage cover by the major tree and shrub species. The vegetation in the study area is depicted on the map (Figure 2. 8 found in the back pocket). The vegetation is classified into six general categories as follows:

Podocarp

Rimu-broadleaved angiosperms

Broadleaved angiosperms

Nothofagus

Valley grass/scrubland

Subalpine/alpine

Bare rock/scree

These categories are based on information in the NZFS Forest Class Map Series 6 Sheets 18 Grey, 19 Canterbury and 20 Westland, as well as the published reports by Burrows (1977a,b); Calder and Wardle (1969); Dunbar (1970); Franklin and Nicholls (1974); Hilgendorf (1935); Kirkland and Trotman (1974); McKelvey (1984); Masters *et al.* (1957); Stewart and Veblen (1982); Wardle (1970a); Wardle and Hayward (1970); and Dr. C.J. Burrows (pers comm). The vegetation types are named after the largest, commonest and most conspicuous species in them.

Far more variation exists than is indicated by the map. To give some indication of this variation for the podocarp and rimu-broadleaved angiosperm types, the numbers in brackets

following the species name in the following descriptions are the range of numbers of stems/ha (derived from actual survey plot data in McKelvey 1984).

PODOCARPS

Podocarps are abundant but canopy broadleaved angiosperms are rare or confined to the understorey. *Dacrydium cupressinum* (rimu) (11-156 stems/ha) is the principal species with occasional *Dacrycarpus dacrydioides* (Kahikatea)(1-224), *Podocarpus hallii* (Hall's totara) (4-90), and *Prumnopitys ferruginea* (miro)(2-65). *Prumnopitys taxifolia* (matai)is rare.

In the understorey are *Ascarina lucida*, *Coprosma* spp., *Griselinia littoralis*, *Myrsine australis*, *Pseudowintera colorata*, *Pseudopanax* spp. and treeferns. *Blechnum* spp., *Gleichenia* spp., and *Polystichum* spp., are common floor species.

RIMU-BROADLEAVED ANGIOSPERMS (Figure 2.9)

Dacrydium cupressinum (9-50) is the main species with *Prumnopitys ferruginea* (2-32) occasional to frequent. The broadleaved angiosperms (*Metrosideros umbellata* (0-28), and *Weinmannia racemosa* (5-59)) are equally prominent. *Quintinia acutifolia* (0-7) occurs occasionally.

The understorey species include *Aristotelia serrata*, *Fuchsia excorticata*, *Myrsine australis*, *Phyllocladus alpinus*, *Pseudopanax* spp., *Ripogonum scandens*, *Coprosma* spp. and treeferns. Floor species include the ferns *Asplenium* spp., *Blechnum* spp., *Hymenophyllum* spp. and *Todea* spp.

BROADLEAVED ANGIOSPERMS

The dominant canopy broadleaved angiosperms are *Metrosideros umbellata*, *Weinmannia racemosa* and *Quintinia acutifolia*. Emergent *Dacrydium cupressinum* and *Prumnopitys ferruginea* may occur on the lower slopes, while on the higher slopes *Libocedrus bidwillii* and *Podocarpus hallii* may be present. Two general categories are distinguished. On the terraces west and south-west of Lake Brunner are former rimu-broadleaved forests in which the rimu has been logged, leaving the broadleaved species as the dominant canopy taxa. On the mountain slopes to the east, the broadleaved angiosperms are the original dominants.

Common understorey species are *Coprosma lucida, Pseudopanax colensoi, P. simplex, Schefflera digitata* and treeferns (*Cyathea smithii*). Ground cover includes *Asplenium bulbiferum, Nertera dichondraefolia, Astelia fragrans, A. nervosa, Blechnum capense* and *Phymatodes diversifolium.*

Figure 2.9 A typical grove of rimu/broadleaved trees on the edge of a clearing in Westland. The picture shows clearly the understorey treeferns, mid-storey broadleaved angiosperm trees and the dominant rimu. Treeferns dominate the forest margin.

Figure 2.10 Isolated patch of *Nothofagus solandri* var. *cliffortioides* with *Podocarpus nivalis* on a scree-slope on Sugar Loaf in the Cass Basin.

NOTHOFAGUS

Westland: In the Otehake basin, the dominant tree is *Nothofagus fusca* with *N. menziesii* and occasional *N. truncata* associated with podocarps and broadleaved angiosperms at the lower altitudes. *N.fusca* and (less commonly) *N. solandri* var. *cliffortioides* and (rarely) *N. menziesii* also occur in the Otira Valley.

Canterbury: *N. solandri* var. *cliffortioides* is the predominant tree up to the timberline, with some *N.fusca* at mid altitude on the slopes from Cora Lynn and Woolshed Hill, to Mt Binser, in the upper Hawdon and Andrews rivers and the Poulter River basin. *N. menziesii* is present in the upper Hawdon and Poulter valleys. An occasional individual of *Podocarpus hallii* is found between 600-1200m, while *Halocarpus bidwillii*, *Phyllocladus alpinus*, *Leptospermum* and *Dracophyllum* are found on bogs and in the upland scrub.

VALLEY GRASS/SCRUBLAND

Westland: Mostly adventive grasses with *Juncus* spp., *Carex* spp. and *Schoenus* spp.. The scrub is composed of *Ulex europaeus*, *Coprosma* spp., *Kunzea ericoides* and tree ferns (mostly *Dicksonia* sp. and some *Cyathea* spp..)

Canterbury: Mainly tussock grassland with adventive grasses. *Festuca novae-zelandiae* is the principal species as well as *Poa colensoi*, *Agrostis capillaris*, and *Anthoxanthum odoratum*. Some areas of *Chionochloa rubra*, tall tussock occur, e.g. near Lake Hawdon. Shrubs are in scattered patches throughout the grassland consisting mainly of *Discaria toumatou*, *Cassinia fulvida*, *Leptospermum scoparium* and some patches of *Cytisus scoparius* , *Coprosma* spp., *Dracophyllum* spp.. and a wide variety of associated herbs and dwarf shrubs.

SUBALPINE-ALPINE

The subalpine-alpine zone is dominated by *Chionochloa;* mainly *C. pallens* with *C. flavescens* near the Main Divide, *C. macra* and *C. rigida* at Porters Pass. Shrubs include *Dracophyllum longifolium*, *D. uniflorum*, *Hebe odora H. subalpina*, *Halocarpus bidwillii*, *H. biformis*, *Phyllocladus alpinus* and *Podocarpus nivalis*. Many other shrub species are present on the Main Divide. Prominent herbs near the Main Divide are *Schoenus pauciflorus*, *Celmisia* spp., but there is a very large number (several hundred) of associated herb and dwarf shrub species. On wet sites *Chionochloa rubra, Carpha alpina*, *Donatia novae-zelandiae*, *Carex* spp. and *Oreobolus* spp. are abundant.

BARE ROCK/SCREE

Bare rock dominates areas above the alpine zone on which snow lies for an extended period of time. Scree slopes are abundant throughout the Cass Basin and further east to Arthur's Pass. They are especially well-developed above the timberline. Isolated patches of grassland, scrub and clumps of *Nothofagus solandri* var. *cliffortioides* may occur across scree-clad slopes (Figure 2.10).

2.2.4 Human Impact

Before the arrival of man to New Zealand, few areas below the tree line were without some form of forest or tall scrubland (McGlone 1983). Human impact in New Zealand was in two stages:
1. Polynesian after their arrival in New Zealand approximately 900 years B.P. (Molloy 1977) and
2. European settlement which began in earnest about 1850.

The Polynesian impact in Westland was minor. Most of the area retained the forest, except for minor clearance close to the coast or on pockets of especially fertile alluvial soils (McGlone 1983).

When the Europeans started to explore Westland in 1860, it was clothed in an unbroken mantle of podocarp and broadleaved angiosperm forest, from the high tide mark to the timberline. This changed with the discovery of gold in 1863. The gold rush began in 1865 and Westland remained New Zealand's largest gold producer until 1895 (May, 1962). When the richer gold deposits were worked out, attention diverted to exploitation of coal and timber resources. All of these activities resulted in the destruction of large tracts of podocarp forest and an opening of the country to farming.

In the Taramakau valley the original forest covered the riverbed except for the main channel. This was cleared by fire in the late 19th Century (Burrows 1974).

The completion of a road over Arthur's Pass in 1866 saw the procession of men to the gold fields in Westland, as well as flocks of sheep to feed them. At the pass the scrub was burnt and the area between Lake Misery and the tarns at the top of the pass were used as a holding paddock (Burrows 1974).

In 1890, a large fire at Arthur's Pass on the Main Divide extended from the left bank of Peg Leg Creek, ascended the Westland spur of Mt Rolleston to a height of 1000 m. It followed the Otira river for approximately 1 kilometre spreading round the Canterbury spur of Mt Rolleston to the scrub line. It destroyed most of the vegetation on the more level portions of the pass except for a few

patches (Cockayne 1898). Though there were fires before and after this time, this fire was the most extensive.

Polynesian fire destroyed the beech forest in the Cass Basin between 500-600 yr B.P.. When the Europeans arrived in the area, most of valley floor was covered in tussock grassland and scrub (Molloy 1977).

The five main sheep runs in the Cass Basin (Craigieburn, Grasmere, Mt White, Castle Hill and Cora Lynn) were established between October 1857 and February 1860 (Acland 1951). Soon after the establishment of these sheep runs, the settlers planted exotic trees such as conifers from North America, eucalypts from Australia as well as broadleaved trees from Europe (Simmonds 1927).

In establishing these runs, much of the scrubland and some beech forest was burned and replaced with tussock grassland, then later with introduced grasses and accidental introductions of weeds. A record of the European burning in the Cass Basin is presented in Table IIA of Molloy (1977).

The adventive plants *Pinus*, *Plantago lanceolata*, *Salix*, *Rumex* and *Taraxacum* type, as well as charcoal in sediments, are important indicators of European settlement of the area.

2.3 LOCATION OF SAMPLING SITES

The initial transect extended from Aickens in Westland to Porters Pass in Canterbury. After the preliminary investigation, the transect was further extended along the Taramakau River to the west coast of the South Island.

2.4 VEGETATION SURVEY

A general description of the vegetation composition on and surrounding the sampling sites is given below. It was derived from personal observations as well as from the following published works: Burrows (1977a,b,c); Dunbar (1970); Moar (1971); Lintott and Burrows (1973); Stewart and Veblen (1982) and Dr. C.J. Burrows (pers comm).

West Coast (Site A)
Sand dunes

Sand dunes bordered on the eastern edge by pastures. *Cotula coronopifolia*, *Plantago lanceolata*, *Rumex acetosella*, *Ulex europaeus* and sedges grow on the site. Some *Pinus* within a kilometre of the site. The nearest continuous natural forest vegetation is over 1 kilometre away on a ridge to the east.

Kumara (Site B)
Scrub/grassland

Predominantly *Dacrydium cupressinum*, within a kilometre to the south. *Weinmannia racemosa, Juncus* spp. and grasses, *Ulex europaeus*, *Coprosma* spp., *Leptospermum scoparium*, Cyperaceae, *Lotus major*, Asteraceae, ferns of *Dicksonia*, *Cyathea*, *Blechnum*, and *Pteridium esculentum* are in the immediate vicinity with some *Pinus* nearby.

Loop Line Road (Site C)
Bog surrounded by forest

Dacrydium cupressinum dominates around the site. Some *Libocedrus bidwillii*, *Podocarpus acutifolius*, *Podocarpus hallii*, *Lagarostrobos colensoi*, *Dacrycarpus dacrydioides*, *Prumnopitys ferruginea*, *Phyllocladus* spp., *Coprosma* spp., *Elaeocarpus* spp., *Metrosideros diffusa, M. umbellata, Quintinia acutifolia*, *Weinmannia racemosa*, are present. On the bog are *Juncus* spp., *Ulex europaeus*, sedges, grasses and the ferns *Pteridium esculentum, Dicksonia* spp., and *Cyathea* spp.

Wainihinihi (Site D)
Grassland and scrub

In the sampling area are *Ulex europaeus*, introduced grasses and *Pteridium esculentum*. On the mountain slopes are *Weinmannia racemosa*, *Dacrydium cupressinum*, *Prumnopitys ferruginea* with some *Dacrycarpus dacrydioides* and the tree ferns, *Dicksonia* spp. and *Cyathea* spp..

Taipo River (Site E)
Grassland and scrub

The dominant tree is *Weinmannia racemosa.* Some *Dacrydium cupressinum*, *Dacrycarpus dacrydioides*, *Aristotelia*, *Elaeocarpus*, *Hedycarya*, *Griselinia*, *Pittosporum eugenioides*, *Schefflera*, *Carpodetus*, *Fuchsia*, *Melicytus*, *Pseudopanax*, *Coprosma* are present. Tree ferns, mostly *Dicksonia* spp., occur with some *Cyathea* spp. in the open and on the lower parts of the mountains.

Jacksons (Site F)
Grassland and scrub

This site is grassland with *Ulex europaeus*, *Pteridium esculentum* and *Polystichum* spp. present. On the lower slopes of the nearby mountains *Weinmannia racemosa* and *Dacrydium cupressinum* dominate. Some *Podocarpus hallii*, *Dacrycarpus dacrydioides*, and *Prumnopitys ferruginea* are present. *Metrosideros umbellata* is upslope as is *Quintinia acutifolia.* Patches of *Nothofagus fusca* occur on river flats. Along the river flats, further up the Taramakau valley, *N. fusca* is more common.

Aickens (Site G)
Grassland and scrub

The site is one kilometre from the mountain slopes. On the river flats, *Nothofagus fusca* dominates with some *Libocedrus bidwillii*, *Podocarpus hallii*, *Prumnopitys taxifolia*, *Pseudowintera colorata*, *Fuchsia excorticata* and *Kunzea ericoides*. Upslope is *Metrosideros umbellata*, with some *Quintinia acutifolia*, *Dacrydium cupressinum*, and *Weinmannia racemosa*. On the lower slopes of the hill is a mixture of *Nothofagus fusca* with *Lagarostrobos colensoi.* On the site are *Polystichum richardii Ranunculus* spp and introduced grasses.

Barrack Creek (Site H) (Figure 2.11)
Opening in the forest

Metrosideros umbellata, and *Weinmannia racemosa* dominate (60%), with *Quintinia acutifolia* also present. A small patch of *Dacrydium cupressinum*, with *Dacrycarpus dacrydioides*, *Prumnopitys ferruginea*, *P. taxifolia* and some *Podocarpus hallii* occurs nearby in a ratio of 1 rimu to all other podocarps. *Coriaria sarmentosa*, *Pseudopanax* spp., and *Hoheria glabrata* are present.

Otira Gorge (Site I)
Scrub and Grassland

The site is 300 m from Barrack Creek. At the site are *Coprosma* spp., *Coriaria sarmentosa*, *Ulex europaeus* and adventive grasses.

Rolleston River (Site J)
Scrub and Grassland

On the river terrace the important shrub and small tree species are *Olearia avicenniaefolia*, *O. arborescens*, *Griselinia littoralis*, numerous *Coprosma* spp., *Pseudopanax colensoi*, *Hebe salicifolia*, *Aristotelia serrata*, and *Pseudowintera colorata*. Upslope is *Metrosideros umbellata* and *Weinmannia racemosa*.

Figure 2.11 Barrack Creek looking south-east towards Mt Philistine in the Southern Alps. In the foreground is the location for site H, while the scrub in middle is site I. The mountain slopes are clad in *Metrosideros umbellata*, *Quintinia acutifolia* and *Weinmannia racemosa*.

Figure 2.12 Lower Bog, at Arthur's Pass on the Main Divide of the Southern Alps.

Main Divide (subalpine) (Sites K-M) (Figure 2.12)
Bog surounded by subalpine scrub and grassland

The principal dominant plants are four species of *Chionochloa.* In the surrounding area *Hoheria glabrata, Halocarpus bidwillii, H. biformis, Podocarpus nivalis, Cassinia vauvilliersii, Dracophyllum longifolium, D. uniflorum, Hebe subalpina, Olearia* spp., *Senecio* spp., *Poa colensoi, Anisotome haastii, Celmisia armstrongii, C. discolor,* and C. *glandulosa* occur. On the bog are *Gentiana bellidifolia, Drosera arcturi, Donatia novae-zelandiae, Carpha alpina, Carex* spp. and *Oreobolus* spp..

Bealey River (Site N)
Small bog in mountain beech forest

The dominant cover on the bog is *Chionochloa rubra, Halocarpus bidwillii* x *biformis, Lepidothamnus laxifolius, Dracophyllum longifolium, Coprosma* spp., *Hebe* spp., *Sphagnum* spp., *Oreobolus pectinatus, Schoenus pauciflorus, Carpha alpina* and *Donatia novae-zelandiae.* In the surrounding forest are *Podocarpus hallii, P. nivalis, Phyllocladus alpinus* and *Libocedrus bidwillii.*

Quarry Knob (Sites O-Q) (Figure 2.13)
Small bog in mountain beech forest

Halocarpus bidwillii and *Phyllocladus alpinus* and sedges grow on the surface of the bog. Near the bog *Leptospermum scoparium* and *Chionochloa rubra* are present. *Podocarpus hallii* occurs in the surrounding forest dominated by *Nothofagus solandri* var. *cliffortioides.*

Bealey Forest (Site R)
Small bog in mountain beech forest

Halocarpus bidwillii, Phyllocladus alpinus and *Chionochloa rubra* grow on and near the bog. *Dracophyllum* spp. grows on the margin of the bog. *Nothofagus solandri* var. *cliffortioides* is dominant.

Woolshed hill (Upper Bog) (Site S)
Small bog in mountain beech forest

Stunted *Nothofagus solandri* var. *cliffortioides* with *Halocarpus bidwillii, Dracophyllum longifolium,* and *Hebe odora* growing on the bog.

Woolshed hill (Lower Bog) (Site T)
Small bog in mountain beech forest

Nothofagus solandri var. *cliffortioides* is the dominant species with some *N. fusca, Aristotelia serrata, Griselinia littoralis, Carpodetus serratus, Pseudopanax crassifolius* only about 300 m away. On the bog are *Phyllocladus alpinus, Halocarpus bidwillii, Leptospermum scoparium, Hebe odora,*

Figure 2.13 Quarry Bog (site Q) surrounded by *Nothofagus solandri* var. *cliffortioides* with *Halocarpus bidwillii* growing on the bog. In the foreground is *Leptospermum scoparium*.

Figure 2.14 A panoramic view over-looking the Cass River towards the Hawdon River.

Cassinia vauvilliersii, *Dracophyllum longifolium*, as well as *Chionochloa rubra*, and some other grasses, *Carex* spp. and other sedges, various dwarf shrubs and small herbs and *Sphagnum cristatum*.

Horrible bog (Sites U, V) (Figure 2.14)
Open marshy area

Schoenus pauciflorus and *Carex* spp. dominate the surface of the bog. *Nothofagus solandri* var. *cliffortioides* occurs on the southern slopes of Mt Horrible. *Discaria toumatou*, *Leptospermum scoparium* and *Cassinia fulvida* occur in patches on the low hills and on ridges surrounding the bog.

Waterfall Terrace (Site W)
Small bog in grassland and scrub

A small sphagnum bog (*S. cristatum*). The surrounding vegetation is as for Horrible Bog.

Cass (Site X)
Grassland

The vegetation at Cass is predominantly *Festuca novae-zelandiae*, with some *Poa colensoi* and adventive grasses. There are scattered areas of scrubland composed of *Cassinia fulvida*, *Discaria toumatou* and *Leptospermum scoparium*.

Misery Swamp (Site Y)
Small bog in grassland and scrub

A small *Sphagnum* bog. The surrounding vegetation is as for Horrible Bog.

Lake Sarah (Sites Z, AA)
Swamp on lake margin

Typha orientalis grows along the margins of the lake. *Phormium tenax*, *Juncus* spp. are present at the southern end of the lake. Grassland surrounds the lake.

Kettlehole bog (Site AB) (Figure 2.15)
Small bog in grassland and scrub

The surrounding vegetation is as for Cass. Species on the bog are mainly *Carex echinata*, *C. sinclairii*, *C. gaudichaudiana*, *Schoenus pauciflorus*, *Haloragis micrantha*, *Sphagnum cristatum* and *S. falcatulum*. On the margin are *Leptospermum scoparium*, *Phormium tenax*, *Juncus gregiflorus* and *Polytrichum formosum*.

Waimakariri (Site AC)
Grassland and scrub

Festuca novae-zelandiae and adventive grasses, are the dominant species. *Discaria toumatou*, *Coprosma* spp. and *Cassinia fulvida* are present.

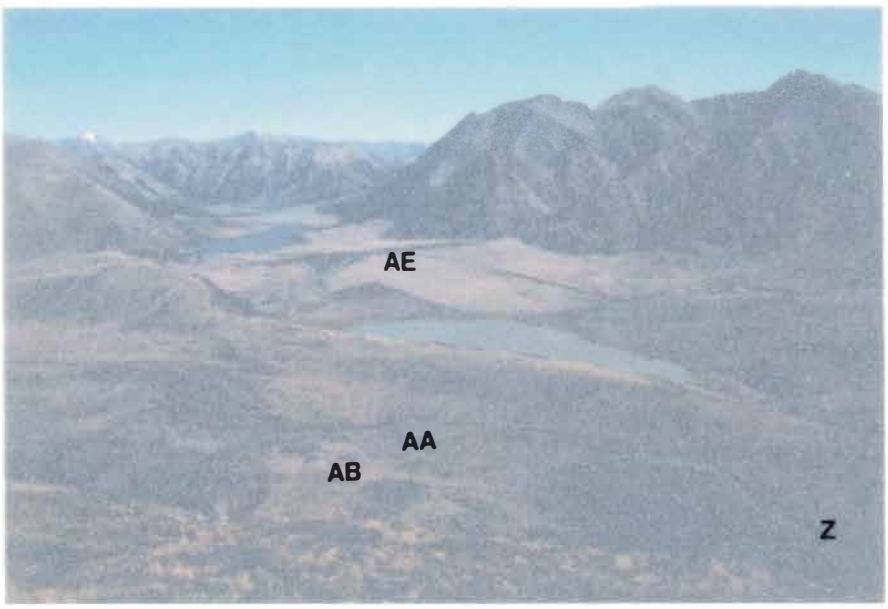


Figure 2.15 A panoramic view from Sugar Loaf looking south to the Craigieburn Ranges. Lake Sarah (foreground), Lake Grassmere (middle) and Lake Pearson (background) all surrounded by pastures with patches of scrub.

Figure 2.16 Lake Hawdon, showing sites AF, and AG. On the margin of the lake are *Phormium tenax* and *Typha orientalis*, all surrounded by *Festuca novae-zelandiae* and adventive grasses.

Figure 2.15 A panoramic view from Sugar Loaf looking south to the Craigieburn Ranges. Lake Sarah (foreground), Lake Grassmere (middle) and Lake Pearson (background) all surrounded by pastures with patches of scrub.

Figure 2.16 Lake Hawdon, showing sites AF, and AG. On the margin of the lake are *Phormium tenax* and *Typha orientalis*, all surrounded by *Festuca novae-zelandiae* and adventive grasses.

St Bernard (Site AD)
Grassland

Festuca novae-zelandiae with adventive grasses dominate.

Ribbonwood Stream (Site AE)
Grassland

Festuca novae-zelandiae with adventive grasses dominate, with scattered patches of *Discaria toumatou*.

Lake Hawdon (Sites AF, AG) (Figure 2.16)
Swamp at lake margin

Festuca novae-zelandiae and adventive grasses dominate the surrounding area, with dense communties of *Phormium tenax* and *Typha orientalis* near the margins of the lake. *Discaria toumatou* is scattered throughout the grassland. *Chionochloa rubra* dominates in the valley to the west.

Slovens Stream (Sites AH, AI)
Grassland

Festuca novae-zelandiae with adventive grasses dominate.

Vagabonds Inn (Site AJ)
Grassland

Festuca novae-zelandiae with adventive grasses dominate.

Craigieburn Cutting (Site AK)
Scrub

Coprosma spp., *Hebe* spp., *Leptospermum scoparium*, *Cassinia fulvida* scrubland near *Nothofagus solandri* var. *cliffortioides* forest. Also present are various herbaceous taxa.

Cave Stream (Site AL) (Figure 2.17)
Small bog in grassland and scrub

Sphagnum bog near *Nothofagus solandri* var. *cliffortioides* forest. Growing on and near the bog are *Discaria toumatou, Leptospermum scoparium*, and *Cassinia fulvida* with *Festuca rubra, Agrostis capillaris, Holcus lanatus, Anisotome aromatica, Celmisia gracilenta, Gaultheria compressa, Hieracium fragile, Gonocarpus* spp, *Ranunculus* spp. *Carex coriacea, C. stellulata, C. sinclairii, Juncus articulatus, J. caespiticius, Schoenus pauciflorus, Blechnum penna-marina, Polytrichum formosum* and *Sphagnum cristatum*.

Castle Hill (Site AM) (Figure 2.18)
Small bog in grassland

Sphagnum bog surrounded by *Festuca novae-zelandiae, Agrostis capillaris, Anthoxanthum odoratum* and other introduced grasses. *Nothofagus solandri* var. *cliffortioides* forest is to the south.

Figure 2.17 Cave Stream looking towards Craigieburn Forest Park.

Figure 2.18 Looking east to the Torlesse Range, note the isolated stands of *Nothofagus solandri* var. *cliffortioides* on the western slopes.

Willow Tree Bog (Site AN) (Figure 2.19)
Small mire in grassland and scrub

Dracophyllum scrub and tussock grassland surrounding a small *Sphagnum* bog. Grasses as for Castle Hill.

Starvation Gully (Site AO)
Grassland and scrub

Dracophyllum acerosum is the prominent plant, with *Chionochloa* cf *rigida*. *Coprosma cheesemanii, C. pseudocuneata, Gaultheria crassa, Celmisia spectabilis*, *Aciphylla* spp. and *Bulbinella* spp. are present.

Porters Pass (Site AP) (Figure 2.20)
Small bog in scrub and grassland

Vegetation in the vicinity is dominated by *Chionochloa flavescens* and *C. rigida* in association with *Dracophyllum acerosum*. *Coriaria sarmentosa* and *Gentiana corymbifera* occur near the site.

2.5 SUMMARY

The study area begins on the low relief of the Westland lowlands, rising abruptly at the Southern Alps, descending to high valley floors at Cass, Broken River and Porters Pass before the descent to the Canterbury Plains in the east.

The climate is highly variable and controlled by a progression of eastward moving anticyclones and depressions. Rainfall is extremely variable and strongly related to topography and is consistent and heavy on the western side of the Southern Alps, reducing eastwards.

Podocarp/broadleaved forests are very diverse occurring on the western side of the study area. They are multi-storied and the main canopy includes tall podocarps; *Dacrycarpus dacrydioides*, *Dacrydium cupressinum*, *Prumnopitys ferruginea* and broadleaved angiosperms; *Metrosideros umbellata*, *Quintinia acutifolia*, *Weinmannia racemosa*. The principal taxa in the understorey are *Aristotelia serrata*, *Coprosma* spp., *Fuchsia excorticata*, *Griselinia littoralis*, *Hoheria* spp., *Phyllocladus alpinus*, *Pseudopanax* spp. and *Pseudowintera* spp.. In the ground layer are a rich variety of ferns and bryophytes.

The beech forest dominates east of the Main Divide on the mountain slopes. Scrubland occurs above the treeline and has a diverse composition. The common taxa are podocarp shrubs, small-leaved *Coprosma* spp., *Dracophyllum* spp., *Hebe* spp., *Pseudopanax* spp. and others. The scrubland gives way to the subalpine and alpine zone which is dominated by *Chionochloa* spp., with

Figure 2.19 Willow tree bog (site AN), 1.5 kilometre west of Lake Lyndon. Predominantly tussock grassland and scrubs.

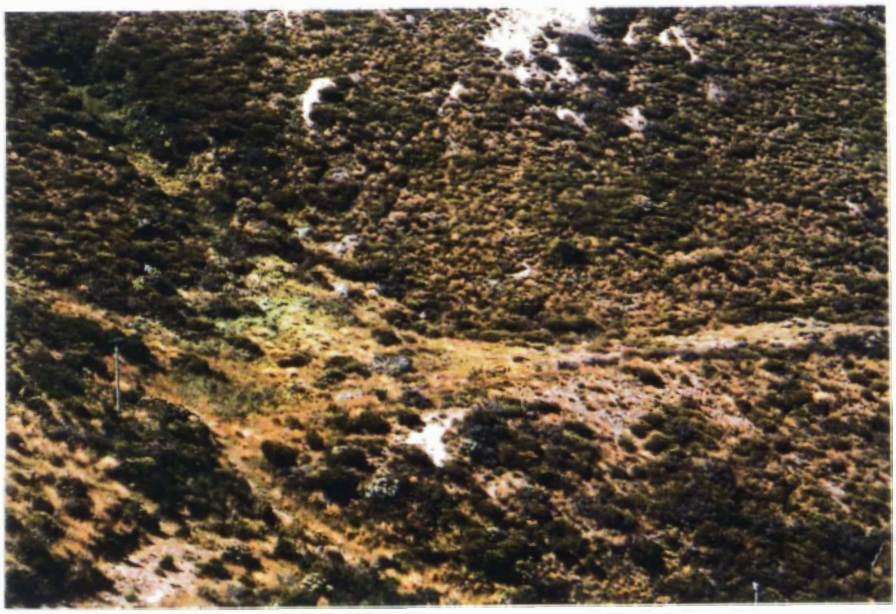


Figure 2.20 Porters Pass (site AP), surrounded by predominantly *Dracophyllum acerosum*.

many herbs and shrubs. The valley floors are dominated by *Festuca novae-zelandiae* and adventive grasses with patches of scrubland with *Discaria toumatou* especially important.

CHAPTER 3
POLLEN TRAPS

3.1 INTRODUCTION

This chapter describes the methods and results for the pollen-trapping experiments. The specific aims were to determine how much pollen is deposited on a seasonal/yearly basis in both forested and non-forested sites, which pollen is redeposited, in what quantities and whether redeposition is a major component of the annual amounts of pollen accumulated.

3.2 DESIGN OF POLLEN TRAPS

The pollen trap designed by Tauber (1967) is the most commonly used apparatus for collecting modern pollen deposition. Hicks and Hyvarinen (1986) reviewed the use of this trap in studies from 1967 to 1983. The Tauber trap was found to be unsuitable for conditions in New Zealand as its efficiency is reduced in high winds (Dr N.T. Moar pers comm). Another drawback of the Tauber trap is that it may act as a trap for insects, frogs and other small animals, thus possibly distorting the pollen accumulation rate (Moar and Myers 1978; Cundill 1986; Hicks and Hyvarinen 1986). Therefore Tauber traps were not used.

The type of trap required was one that fulfilled the following criteria: that it "should simulate, as nearly as possible, the manner in which pollen is trapped at the surface of bogs and lakes." (Lewis and Ogden 1965, p614).

As it was planned to use more then one trap per site, a simple, inexpensive, yet robust trap was required. A trap modified from that of Cundill (1986) was designed. It (Figure 3.1) consists of a plastic pottle with a Petri dish at the top. The Petri dish contained six holes in its base for the drainage of water. On top of this base are two layers of capillary matting cloth overlying a glass fibre filter to prevent pollen from being washed through. The Petri dish is held in position by three wires. These wires, while not interfering with pollen deposition, keep the capillary matting cloth in the Petri dish and the Petri dish attached to the pottle, but prevent *Nestor notabilis* (Keas) (Figure 3.2) from removing the collecting medium. The major component of the trap is the Petri dish; the pottle is required only to secure the Petri dish in place.

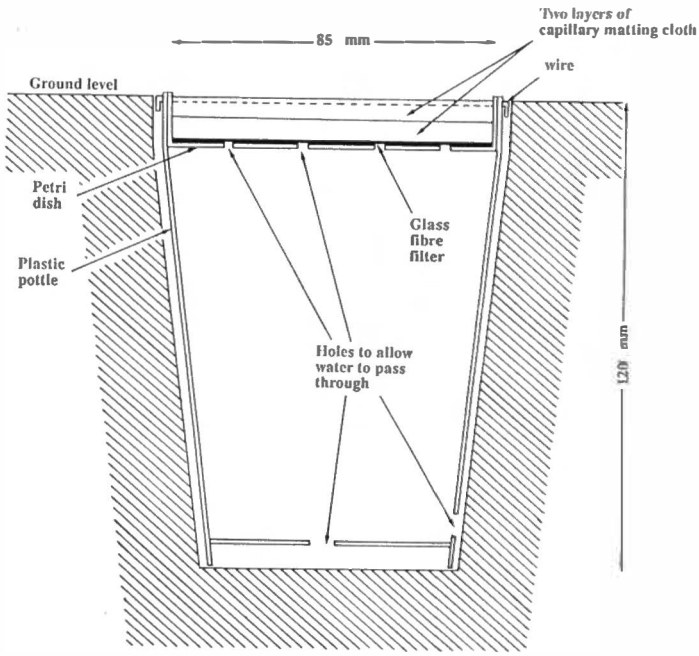


Figure 3.1 Schematic diagram of the pollen trap used to collect pollen deposition.

3.3 LOCATION OF POLLEN TRAPS

Pollen traps were placed in seven locations from Otira, Westland to Craigieburn, Canterbury (Table 3.1, Figure 2.8). The sites chosen were representative of the vegetation in the area. Also they were selected to sample areas at varying distances from major tree species.

Table 3.1. Location of the pollen traps.

Location	Site
Barrack Creek	H
Otira Gorge	I
Rolleston River	J
Lower Bog, Main Divide	K
Bealey River	N
Lake Hawdon	AF
Cave Stream	AL

Six pollen traps were randomly distributed throughout each of the sites, except for site H and I which had only three traps. These two sites were 500m apart: site H, consisting of bare rock along Barrack Creek and site I, situated in a small opening surrounded by scrubland. The traps were positioned such that the openings were at ground level so that the accumulation rates obtained would be most comparable to those for a moss polster (Lewis and Ogden 1965; Cundill 1986; Hicks and Hyvarinen 1986) (Figure 3.3).

Figure 3.2 *Nestor notabilis* (Kea). The scourge of the researcher in subalpine/alpine locations.

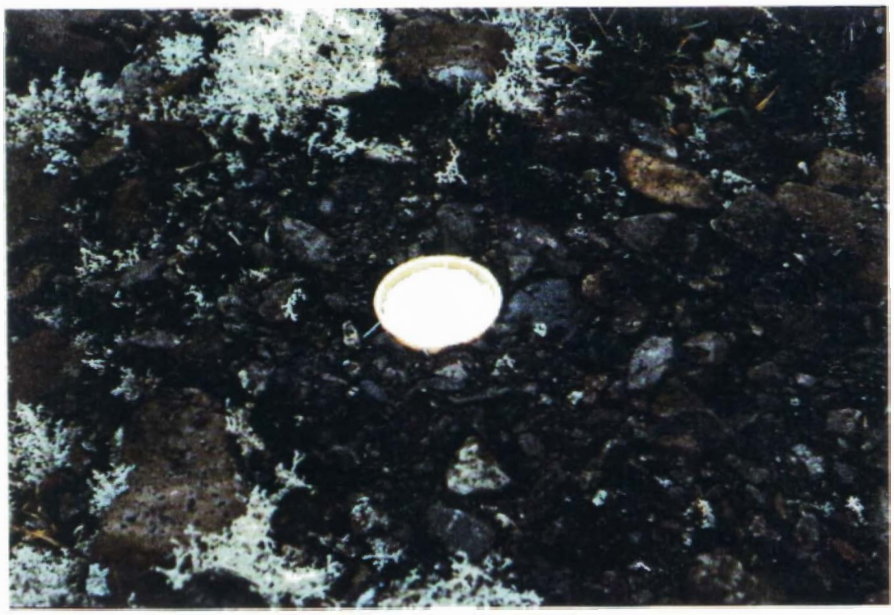


Figure 3.3 One of the settings for the pollen traps at Rolleston River. An attempt was made to clear an area around the trap, when possible. The later traps had three wires holding the matting cloth in place.

Traps were placed at each site at the beginning of October 1987, before spring flowering and were collected four times during the year at the end of each of the following arbitrary "deposition seasons":

1.	Spring	October-December 1987	]The main flowering
2.	Summer	January-March 1988	]season
3.	Autumn	April-June 1988	[Redeposition
4.	Winter	July-September 1988	[season.

During each collection the medium and filter were removed, placed into new plastic bags, labelled and sealed. The Petri dish was washed out with distilled water and the medium and filter were replaced. A later modification of the trap was to have the Petri dish detachable, which allowed the whole dish to be removed and a new one inserted into the pottle. This not only reduced the time needed to collect the sample, but also prevented any contamination between seasons. The samples were stored at 4^0 C until required for laboratory analysis.

3.4 METHOD OF POLLEN PREPARATION

Flenley (1973) and Cundill (1986) used acetate wool as the collecting medium, as it dissolves in acetone. This material was not available, so capillary matting cloth was substituted as the collecting medium. The capillary matting cloth has a rough texture, is 4mm thick and is readily available. However, the main drawback with the cloth is that although it dissolves in concentrated H_2SO_4, it produces an insoluble precipitate which hinders pollen recovery. This was not considered a problem, as moss polsters and peat were not dissolved either, but during preparation were soaked in 5% sodium hydroxide and vigorously agitated. To calculate an 'absolute' value for the pollen accumulation rates, a spore marker utilising the method of Stockmarr (1971) was used.

Two *Lycopodium* tablets containing 10 850 $\pm$ 200 spores were added at the start of the pollen preparation. The capillary matting cloth was cut into three pieces and placed into a beaker along with the glass fibre filter. These were treated with 5% sodium hydroxide for 10 minutes in a boiling water bath, during which time the sample was vigorously agitated. It was then thoroughly rinsed with distilled water prior to being sieved. The resulting residue was treated with hot 40% hydrofluoric acid to remove silicates, followed by standard acetolysis (Faegri and Iversen 1964). The residue was stained with 1% aqueous safranin. One drop of residue was added to four drops of melted glycerine jelly and thoroughly mixed on the slide, prior to the addition of a cover slip.

The slides were each placed in the same relative position on the mechanical stage of an Olympus BH-2 microscope. After each traverse the slide was moved vertically by one division of the vernier to prevent the overlap of the field of view. In this way, traverses were positioned evenly over the slide to avoid any effect of non-random distribution of pollen and spores (Brookes and Thomas 1967). The number of traverses varied between slides, with as many as necessary until a total of 700 pollen and spores of all types were counted, plus the number of marker *Lycopodium*.

Pollen counting was carried out at a magnification of x400, with critical identification at x1000. The identification of pollen and spores was by comparison of sample material with specimens in the modern reference collection held at D.S.I.R. Lincoln. The published work of Cranwell (1953) and the pollen morphology studies of gymnosperms by Pocknall (1981a,b,c) were also used for reference. Slides containing material of known species, prepared in the same way as the sub-fossil material, were also used (Moore and Webb 1978; Birks and Gordon 1985).

Pollen grains were identified to the lowest possible taxonomic level. Many pollen types were identifiable only to the family level: Apiaceae, Asteraceae, Cyperaceae, Epacridaceae, Poaceae. Some were identifiable to generic level: most of the Podocarpaceae (Pocknall 1981a,b,c), *Coprosma*, *Coriaria*, *Metrosideros*, *Nothofagus fusca* type (includes *N. fusca*, *N. solandri* var. *cliffortioides*, *N. solandri* var. *solandri*, and *N. truncata*), *Pinus*, *Quintinia, Weinmannia*, *Rumex*. A few could be identified to species; *Dacrydium cupressinum*, *Dacrycarpus dacrydioides*, *Nothofagus menziesii*. Nomenclature follows Allan (1961) with revisions in Connor and Edgar (1987) and Webb *et al.* (1988).

3.5 NUMERICAL ANALYSIS

3.5.1 95% Confidence Intervals

To assist the pollen analyst to determine the precision of pollen data, Mosimann (1965) has compiled a number of statistical tests. These tests apply 95% confidence intervals for counts made both inside (counting to a fixed number of pollen and spores) and outside (number of grains observed while counting to a fixed number) the pollen sum. The use of these methods is discussed in detail by Maher (1972a). Computer programs, written in Basic, supplied by Dr L. Maher Jr., Geology Department, University of Wisconsin, based on the statistical tests in Mosimann (1965) and in Maher (1981) were used to combine pollen counts, determine accumulation rates, as well as 95%

intervals and test the null hypothesis. To provide a reliable result and reduce the confidence interval, it is necessary to count 100 markers while counting to the pollen sum. There are two ways in which to reduce the confidence interval: 1. to increase the pollen count; 2. add more *Lycopodium* tablets to the sample (Maher 1981). Since all the samples had been processed prior to obtaining this latter information, the pollen count was increased on a number of samples in which there were less than 100 markers, until a minimum of 100 markers were counted.

3.5.2 Numerical Methods

Numerical methods in modern pollen analyses are useful for the detection, summarisation and display of any major pattern within a modern pollen data set. For reviews of theory and methods of numerical methods used in palynology see Prentice (1980) and Birks and Gordon (1985).

In this study two numerical methods, Principal Components Analysis (PCA) and Clustering Analysis (CA) were used.

Principal Components Analysis

PCA is the most widely used of the ordination methods (Prentice 1980). PCA derives a number of linear combinations from a data set that retains as much of the information in the original data as possible (SAS manual 1987). The first principal component accounts for the maximum possible proportion of the total variance in a data set, the second principal component for the maximum possible proportion of the remaining variance, and so on until all of the variance is accounted for. If there is any structure within the data set, the first few principal components will account for most of the variability in the data (Prentice 1980).

Cluster Analysis

CA places objects into clusters that are suggested by the data, not defined *a priori* (Manly 1986, SAS manual 1987). For this study two methods of CA were used: Single Linkage and Group Average Linkage.

Single linkage imposes no constraints on the shape of the cluster but sacrifices performance in the recovery of compact clusters in return for the ability to detect elongated and irregular clusters (SAS manual 1987). This could lead to chaining and long straggly clusters.

Group average linkage (unweighted pair-group method using arithmetic averages (UPGMA)) is slightly biased towards finding clusters of equal variance (SAS manual 1987), but reduces the amount of chaining. It is probably the most useful. Occasionally, single linkage may be

more useful than group average linkage because of its tendency to find chains of closely related groups (Sneath and Sokal 1973).

PCA gives a reliable representation between groups but is not reliable within the groups. Cluster analysis estimates reasonably the similarities within clusters but becomes unreliable between clusters (Sneath and Sokal 1973). Together the two methods should complement each other.

3.6 RESULTS

Unfortunately, some traps were damaged during the sampling period e.g. collecting medium being pulled out of the traps, traps being pulled out of the ground, broken, removed or turned upside down. The causes of this destruction are uncertain, but may possibly be due to animals (e.g. Keas) and/or humans. At Rolleston River, the autumn collection was reduced to one trap because the river flooded and the new river now flows through the sample area. Only those traps which were in an upright position were considered undamaged. All traps were replaced and repositioned for the next deposition period.

Table 3.2 The number of undamaged traps collected site^{-1} season^{-1}.

Site	Spring	Summer	Autumn	Winter
Barrack Creek	2	3	3	3
Otira Gorge	2	3	3	3
Rolleston River	4	5	1	2
Main Divide	3	1	5	2
Bealey River	6	6	6	5
Lake Hawdon	1	4	5	2
Cave Stream	6	6	3	5

3.6.1 Pollen Accumulation Rates (PAR)

The pollen accumulation rate (PAR) for any taxon cm^{-2} is as follows:

$$PAR = \frac{21700 \times \#\text{ of grains counted}}{\text{number of markers counted}} \div \text{by } 56.7\ cm^2$$

where 21700 = the number of markers added to the sample
56.7 cm^2 = the area of the trapping surface.

Seasonal Accumulation Rates

The pollen counts from each of the traps per season per site were combined to determine the average accumulation rate for each species. The number of traps combined depended on the number which were collected undamaged (Table 3.2). The results were combined using the program

Table 3.3 Seasonal pollen accumulation rates cm-2 by species at the seven locations. Only major species shown.

TAXON	Barrack Creek				Otira Gorge				Rolleston River				Main Divide			
	Sp	Su	Au	Wn	Sp	Su	Au	Wn	Sp	Su	Au	Wn	Sp	Su	Au	Wn
Dacrydium cupressinum	67	23	1	2	19	22	2	2	38	28	3	-	30	1	2	1
Prumnopitys	-	-	3	-	-	-	1	1	-	3	2	-	-	-	2	3
Pinus	15	18	3	12	8	17	-	5	32	19	5	15	11	9	9	48
Phyllocladus	48	-	1	-	63	-	3	-	57	2	2	1	50	-	1	1
Metrosideros	73	26994	269	183	79	9826	378	100	27	93	30	6	10	29	3	12
Nothofagus fusca type	118	-	2	5	121	11	5	4	160	7	4	9	340	9	7	16
Quintinia	32	243	4	5	53	54	13	-	46	-	-	-	17	-	-	-
Weinmannia	85	874	30	13	204	549	32	11	104	13	3	-	42	12	-	2
Coprosma	60	-	2	193	1160	22	13	356	88	7	9	786	282	55	25	42
Asteraceae	7	64	2	4	10	-	5	3	120	47	3	4	12	48	3	3
Coriaria	1651	23	20	10	1359	62	18	7	559	34	6	1	17	4	1	2
Cyperaceae	9	-	-	-	12	-	-	-	4	-	-	-	471	105	7	10
Poaceae	438	413	15	34	4142	1599	110	23	1054	306	13	10	192	528	26	25
Taraxacum type	22	157	7	4	63	207	15	4	39	87	3	3	4	8	1	1
Maximum pollen/cm2	2995	30089	438	739	7695	13671	702	851	2712	1136	149	947	1828	917	211	264

TAXON	Bealey River				Lake Hawdon				Cave Stream			
	Sp	Su	Au	Wn	Sp	Su	Au	Wn	Sp	Su	Au	Wn
Dacrydium cupressinum	23	8	1	1	4	17	2	3	-	7	3	1
Prumnopitys	4	1	1	2	4	-	-	3	-	-	3	1
Pinus	8	11	2	4	61	22	14	1	23	13	21	41
Phyllocladus	65	2	-	1	8	-	1	3	20	-	2	1
Metrosideros	13	17	3	3	-	-	-	-	-	-	-	2
Nothofagus fusca type	753	24	11	11	961	40	17	18	1275	56	46	17
Quintinia	10	-	-	-	-	-	-	-	-	-	-	-
Weinmannia	13	3	-	-	-	-	-	-	-	-	-	-
Coprosma	142	10	1	17	100	-	1	65	71	5	3	55
Asteraceae	9	4	1	2	4	9	2	3	10	949	86	7
Coriaria	9	1	-	-	-	-	-	-	-	-	-	-
Cyperaceae	75	2	2	9	968	43	34	40	428	63	9	5
Poaceae	111	84	11	6	2350	948	77	72	1917	1648	166	31
Taraxacum type	2	7	1	1	19	1718	15	9	39	1082	10	4
Maximum pollen/cm2	1502	278	75	104	4623	3534	260	270	4352	4410	513	211

Combine.bas which makes it possible to determine the average accumulation rate as well as the 95% confidence intervals for each species per season per site (Maher 1981 Table III p186). The geometric means of the species' accumulation rate per cm^2 per season per site are shown in Table 3.3.

Podocarpaceae

Dacrydium cupressinum in the Westland sites has the same PAR for the spring and summer sampling period. On the Main Divide and Bealey River sites the main deposition period is in the spring. Sites further to the east only receive a low amount of rimu pollen throughout the year. *Prumnopitys* was collected in only trace amounts at all sample sites. The main deposition of *Phyllocladus* is in the spring at all sites, with only small amounts redeposited.

Angiosperm Trees and Shrubs

The main deposition of *Metrosideros* occurs in the summer with the highest PAR at Barrack Creek. At Barrack Creek and Otira Gorge, *Metrosideros* is important as redeposited pollen. *Nothofagus fusca* type is mainly deposited in the spring, with some redeposition. The spring and summer deposition of *Quintinia* is local, decreasing rapidly eastwards. The summer deposition of *Weinmannia*, like *Quintinia*, decreases rapidly eastwards. *Coprosma* has high PAR in spring with an increase during the 'winter'.

Non-arboreal Pollen

Asteraceae is a minor component of the pollen deposition, except at Cave Stream in summer. The main deposition of *Taraxacum* type is in summer, with only minor redeposition of pollen in autumn and winter. *Coriaria* is important in the spring at the Westland sites, whereas Cyperaceae is important at the Main Divide and the two grassland sites in the east during this time. Poaceae is deposited in spring and summer. The herbaceous pollen is important only in the grassland.

Annual Accumulation Rates

The combined annual accumulation rates for the major species, with 95% confidence limits, are shown in Table 3.4. The program Nulconc.bas (Maher 1981 Table II, p184) was used to tests the null hypothesis (that the difference between the two estimates result simply from chance variability expected in samples with the same pollen concentration) (Figure 3.4). This assists in determining whether the variation of a taxon between the sites is statistically the same or different at the 0.05 level.

Table 3.4 Pollen Traps Yearly pollen accumulation rate cm^{-2}.

95% confidence limits are shown (Upper (u), mean (x) and lower (l)). Only major taxa shown.

Species		Barrack Creek	Otira Gorge	Rolleston River	Main Divide	Bealey River	Lake Hawdon	Cave Stream
	u	166	92	95	58	42	63	19
Dacrydium	x	**93**	**45**	**69**	**34**	**33**	**26**	**11**
cupressinum	l	59	22	52	22	25	13	6
	u	5	7	10	9	15	33	7
Prumnopitys	x	**3**	**2**	**5**	**5**	**8**	**7**	**4**
	l	2	0	2	2	5	2	1
	u	107	71	106	107	35	157	128
Pinus	x	**48**	**30**	**71**	**77**	**25**	**98**	**98**
	l	24	13	48	56	19	62	78
	u	70	96	89	71	80	38	36
Phyllocladus	x	**48**	**66**	**62**	**52**	**68**	**12**	**23**
	l	33	44	46	38	56	3	16
	u	35411	12380	197	88	47		3
Metrosideros	x	**27519**	**10383**	**156**	**54**	**36**	**Trace**	**2**
	l	21397	8714	125	34	29		2
	u	165	208	225	440	865	1316	1541
Nothofagus	x	**125**	**141**	**180**	**372**	**799**	**1036**	**1394**
fusca Type	l	94	100	145	318	738	815	1262
	u	428	172	65	27	16		
Quintinia	x	**284**	**120**	**46**	**17**	**10**	**Trace**	**Trace**
	l	187	62	35	11	6		
	u	1352	1006	152	83	23	Not	
Weinmannia	x	**1002**	**796**	**120**	**56**	**16**		**Trace**
	l	743	629	94	38	11	Observed	
	u	306	1826	1011	480	192	232	162
Coprosma	x	**255**	**1551**	**890**	**404**	**170**	**166**	**134**
	l	215	1325	785	341	150	121	113
	u	156	44	218	98	23	54	1170
Asteraceae	x	**77**	**18**	**174**	**66**	**16**	**17**	**1052**
	l	38	8	140	44	11	8	953
	u	2008	1754	691	44	17		
Coriaria	x	**1704**	**1446**	**600**	**24**	**10**	**Trace**	**Trace**
	l	1463	1207	525	13	7		
	u	20	27	10	697	104	1373	577
Cyperaceae	x	**9**	**12**	**4**	**593**	**88**	**1085**	**505**
	l	4	5	2	506	73	857	443
	u	1170	6899	1552	904	235	4146	4114
Poaceae	x	**900**	**5874**	**1383**	**771**	**212**	**3447**	**3762**
	l	696	5003	1236	659	190	2871	3440
	u	305	398	170	33	16	1990	1263
Taraxacum	x	**190**	**289**	**132**	**14**	**11**	**1761**	**1135**
Type	l	118	208	104	5	7	1569	1021

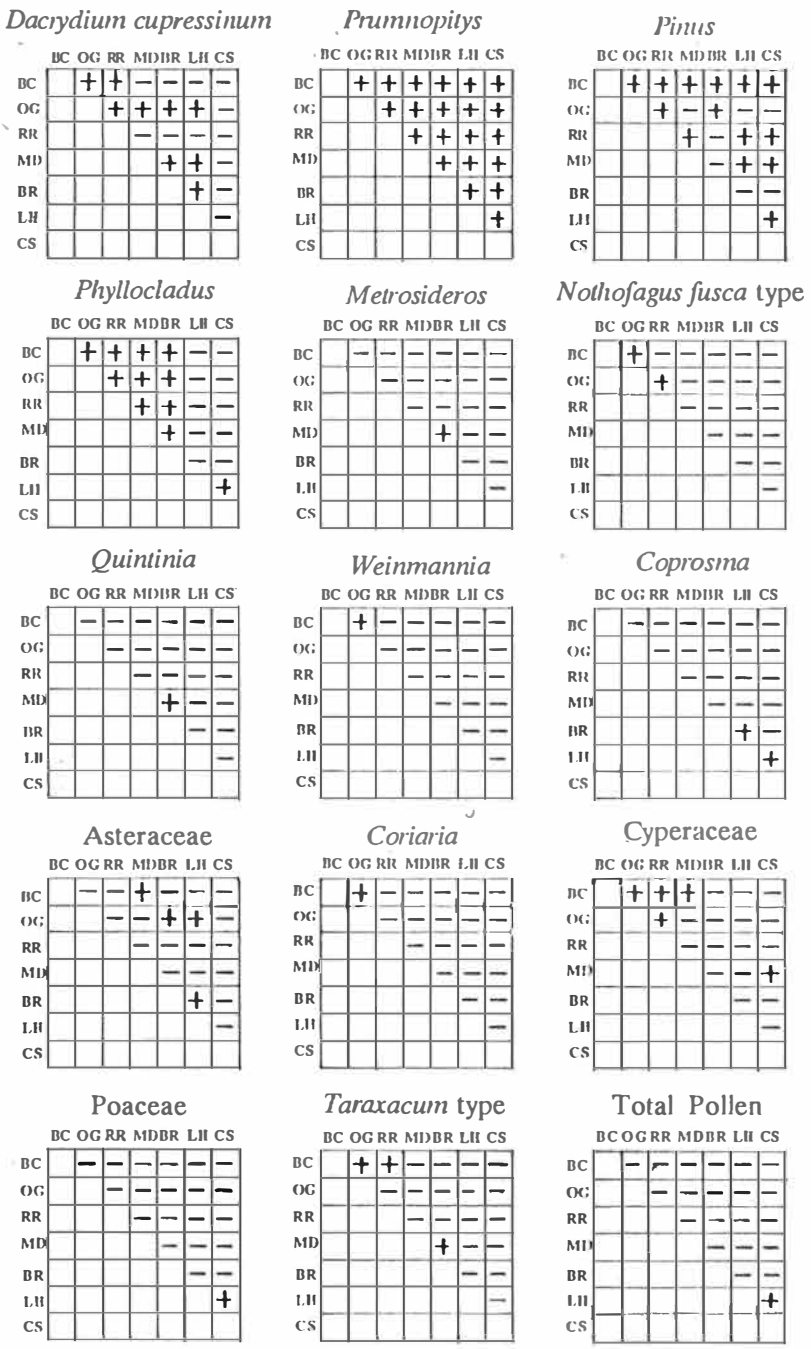


Figure 3.4 Indication of whether the pollen accumulation rate are the same for a taxon between the different sites. Same (+), different (-). (Based on the null hypothesis using the program Nulconc.bas in Maher 1981).

The features of the annual pollen accumulation rate are:

1. *Dacrydium cupressinum* has similar PAR at the three Westland sites, with total quantities decreasing eastward. The deposition of *Dacrydium cupressinum* at Main Divide and Bealey River are the same as for Otira Gorge.;

2. The PAR for *Prumnopitys* is unreliable due to low the pollen count (<4).;

3. The PAR of *Pinus* at Barrack Creek is the same as for all the other sites. The value at Bealey River is the same as for Barrack Creek and Otira Gorge but not for the other sites.;

4. *Phyllocladus* has the same PAR at all sites except for Lake Hawdon and Cave Stream which have similar rates to one another.;

5. The deposition rates of *Metrosideros* (a bird pollinated species also visited by bees) decreases rapidly over a very short distance. Main Divide and Bealey River have the same accumulation rate and *Quintinia* displays the same pattern.;

6. Barrack Creek and Otira Gorge have the same PAR for *Weinmannia*, and the total quantities decrease eastwards.;

7. The PAR for *Nothofagus fusca* type increases as one goes from the beech forest (Bealey River) to the grassland sites (Lake Hawdon and Cave Stream) to the east.

8. Only at Lake Hawdon and Cave Stream is the PAR for Poaceae the same.

The seasonal and annual accumulation rates of all pollen types per site are shown in Figure 3.5. The 95% confidence intervals for the seasonal and annual PAR are shown in Table 3.5.

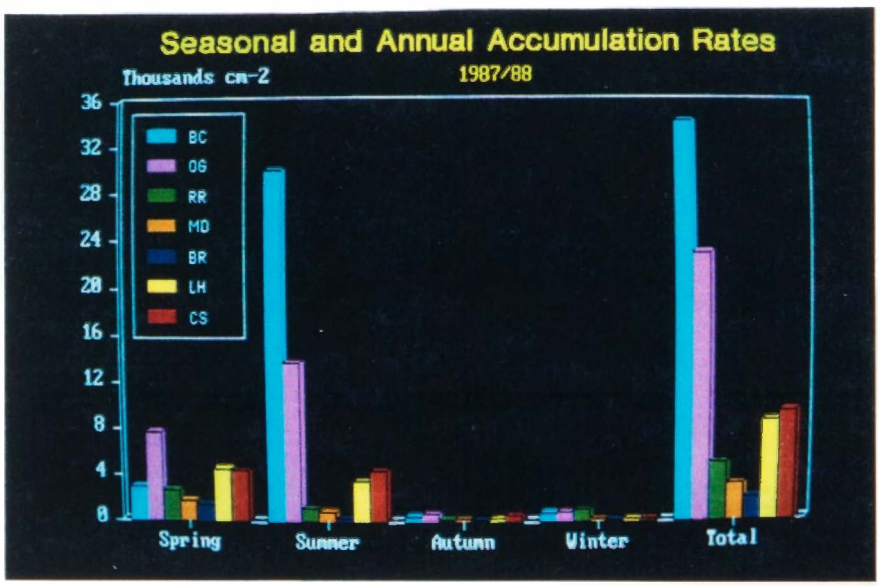


Figure 3.5 Total seasonal and annual pollen accumulation rates cm^{-2} at all seven locations. BC = Barrack Creek; OG = Otira Gorge; RR = Rolleston River; MD = Main Divide; BR = Bealey River; LH = Lake Hawdon; CS = Cave Stream.

Table 3.5 Total accumulation rates cm^{-2} $season^{-1}$ with 95% confidence limits. Based on all pollen and spores. (u = upper limit, x = mean; l = lower limit).

Season		Spring	Summer	Autumn	Winter	Total
Site						
	u	3428	38798	468	803	43261
Barrack Creek	x	**2995**	**30089**	**438**	**739**	**34261**
	l	2617	23334	410	680	27041
	u	8890	16311	759	925	26885
Otira Gorge	x	**7695**	**13671**	**702**	**851**	**22919**
	l	6659	11458	649	782	19548
	u	3006	1220	170	1053	5449
Rolleston River	x	**2712**	**1136**	**149**	**947**	**4944**
	l	2448	1057	131	852	4488
	u	2026	1057	223	291	3597
Main Divide	x	**1828**	**917**	**211**	**264**	**3220**
	l	1650	796	199	240	2885
	u	1609	292	79	110	2090
Bealey River	x	**1502**	**278**	**75**	**104**	**1959**
	l	1401	264	70	99	1834
	u	5691	3913	278	298	10180
Lake Hawdon	x	**4623**	**3534**	**260**	**270**	**8687**
	l	3756	3192	244	244	7436
	u	4737	4800	552	220	10309
Cave Stream	x	**4352**	**4410**	**513**	**211**	**9386**
	l	3999	4052	478	202	8731

The main features of the seasonal and annual accumulation rates are:

1. Pollen accumulation rates differ over the different seasons. Major deposition occurs in one particular season for each site: spring for Rolleston River, Main Divide, and Bealey River; summer for Barrack Creek and Otira Gorge, while at Lake Hawdon and Cave Stream deposition occurs in both spring and summer. This reflects the pollen production characteristics of the main vegetation type in the area surrounding each of the sampling sites;

2. Low PAR in the summer at Rolleston River, Main Divide and Bealey River;

3. Similar low PAR for autumn and winter representing between 1-10% of the total annual accumulation, except at Rolleston River; and

4. The total annual accumulation rate varies from site to site. The highest PAR occurs at Barrack Creek and Otira Gorge (20000-35000 cm^{-2}), then Lake Hawdon and Cave Stream (8000 - 9000 cm^{-2}), the Main Divide (3000 cm^{-2}) and the lowest value at Bealey River in the *Nothofagus* forest (2000 cm^{-2}).

Table 3.6 Pollen percentage data based on the seasonal accumulation rates (cm^{-2}). Only major species shown, based on all pollen and spores counted. + = trace. - = not observed.

	Barrack Creek				Otira Gorge				Rolleston River				Main Divide			
Taxon	Sp	Su	Au	Wn	Sp	Su	Au	Wn	Sp	Su	Au	Wn	Sp	Su	Au	Wn
Dacrydium cupressinum	2.2	0.1	0.2	0.3	0.2	0.2	0.3	0.2	1.4	2.5	2.0	-	1.6	0.1	0.9	0.4
Prumnopitys	+	-	0.7	+	+	-	0.1	0.1	+	0.3	1.3	-	-	-	0.9	1.1
Pinus	0.5	0.1	0.7	1.6	0.1	0.1	+	0.6	1.2	1.7	3.4	1.6	0.6	1.0	4.3	18.2
Phyllocladus	1.6	-	0.2	0.0	0.8	0.0	0.4	+	2.1	0.2	1.3	0.1	2.7	-	0.5	0.4
Metrosideros	2.4	89.7	61.4	24.8	1.0	71.9	53.8	11.8	1.0	8.2	20.1	0.6	0.5	3.2	1.4	4.5
Nothofagus fusca type	3.9	-	0.5	0.7	1.6	0.1	0.7	0.5	5.9	0.6	2.7	1.0	18.6	1.0	3.3	6.1
Quintinia	1.1	0.8	0.9	0.7	0.7	0.4	1.9	+	1.7	+	+	-	0.9	-	-	-
Weinmannia	2.8	2.9	6.8	1.8	2.7	4.0	4.6	1.3	3.8	1.1	2.0	-	2.3	1.3	-	0.8
Coprosma	2.0	-	0.5	26.1	15.1	0.2	1.9	41.8	3.2	0.6	6.0	83.0	15.4	6.0	11.8	15.9
Asteraceae	0.2	0.2	0.5	0.5	0.1	+	0.7	0.4	4.4	4.1	2.0	0.4	0.7	5.2	1.4	1.1
Coriaria	55.1	0.1	4.6	1.4	17.7	0.5	2.6	0.8	20.6	3.0	4.0	0.1	0.9	0.4	0.5	0.8
Cyperaceae	0.3	-	-	+	0.2	-	-	-0.1	+	-	-	-	25.8	11.5	3.3	3.8
Poaceae	14.6	1.4	3.4	4.6	53.8	11.7	15.7	2.7	38.9	26.9	8.7	1.1	10.5	57.6	12.3	9.5
Taraxacum type	0.7	0.5	1.6	0.5	0.8	1.5	2.1	0.5	1.4	7.7	2.0	0.3	0.2	0.9	0.5	0.4

	Bealey River				Lake Hawdon				Cave Stream			
Taxon	Sp	Su	Au	Wn	Sp	Su	Au	Wn	Sp	Su	Au	Wn
Dacrydium cupressinum	1.5	2.9	1.3	1.0	0.1	0.5	0.8	1.1	+	0.2	0.6	0.5
Prumnopitys	0.3	0.4	1.3	1.9	0.1	+	+	1.1	+	-	0.6	0.5
Pinus	0.5	4.0	2.7	3.8	1.3	0.6	5.4	0.4	0.5	0.3	4.1	19.4
Phyllocladus	4.3	0.7	+	1.0	0.2	+	0.4	1.1	0.5	-	0.4	0.5
Metrosideros	0.9	6.1	4.0	2.9	-	+	+	+	-	+	+	0.9
Nothofagus fusca type	50.1	8.6	14.7	10.6	20.8	1.1	6.5	6.7	29.3	1.3	9.0	8.1
Quintinia	0.7	+	+	+	+	-	-	-	+	+	-	+
Weinmannia	0.9	1.1	+	+	-	-	-	-	+	-	-	+
Coprosma	9.5	3.6	1.3	16.3	2.2	+	0.4	24.1	1.6	0.1	0.6	26.1
Asteraceae	0.6	1.4	1.3	1.9	0.1	0.3	0.8	1.1	0.2	21.5	16.8	3.3
Coriaria	0.6	0.4	+	+	-	+	+	-	+	+	+	-
Cyperaceae	5.0	0.7	2.7	8.7	20.9	1.2	13.1	14.8	9.8	1.4	1.8	2.4
Poaceae	7.4	30.2	14.7	5.8	50.8	26.8	29.6	26.7	44.0	37.4	32.4	14.7
Taraxacum type	0.1	2.5	1.3	1.0	0.4	48.6	5.8	3.3	0.9	24.5	1.9	1.9

3.6.2 Accumulation Rates vs percentage

Pollen percentage data should present a different perspective as it removes the effects of differing total numbers of pollen grains. However, due to the fact that the pollen sum must equal 100%, species are interdependent because when one species percentage increases, another must decrease. The seasonal pollen percentage values are displayed in Table 3.6 and the annual percentage in Table 3.7.

Seasonal

During the flowering period, the taxa of local origin are represented by a high percentage of pollen in the traps during either the spring or summer.

Locally derived pollen, also have high redeposition percentages, while pollen from the regional component have low redeposition percentages.

Table 3.7 Pollen % based on annual accumulation rate. Only major taxa shown. + = less than 1%

Site	BC	OG	RR	MD	BR	LH	CS
Taxa							
Dacrydium cupressinum	+	+	1	1	2	+	+
Prumnopitys	+	+	+	+	+	+	+
Pinus	+	+	1	2	1	1	1
Phyllocladus	+	+	1	2	3	+	+
Metrosideros	80	45	3	2	2	+	+
Nothofagus fusca Type	+	1	4	12	41	12	15
Quintinia	1	+	1	1	1	+	+
Weinmannia	3	3	2	2	1	+	+
Coprosma	1	7	18	13	9	2	1
Asteraceae	+	+	4	2	1	+	11
Coriaria	5	6	12	1	1	+	+
Cyperaceae	+	+	+	18	4	12	5
Poaceae	3	26	28	24	11	40	40
Taraxacum Type	1	1	3	+	1	20	12

Annual

A comparison between the annual accumulation rates and the annual percentage values show that:

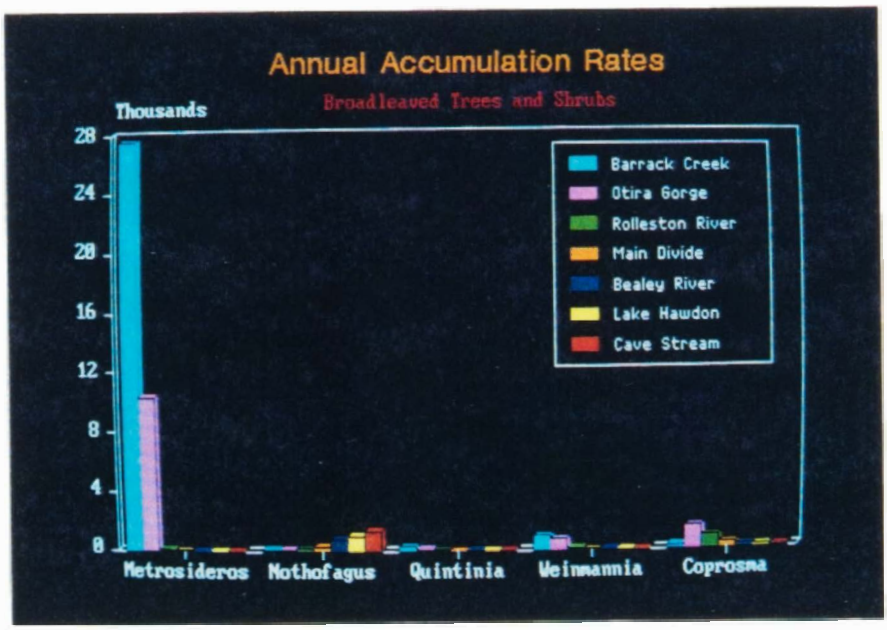
For the angiosperm trees and shrubs (Figure 3.6)

1. The broadleaved angiosperms *Metrosideros*, *Quintinia* and *Weinmannia* have the same pattern in both.

2. *Nothofagus fusca* type has increasing PAR away from the beech forest, while the percentage is highest at Bealey River, and Main Divide, Lake Hawdon, and Cave Stream have similar, low percentage representation.

3. *Coprosma* has its highest PAR at Otira Gorge, while the percentage value is highest at Rolleston River.

a



b

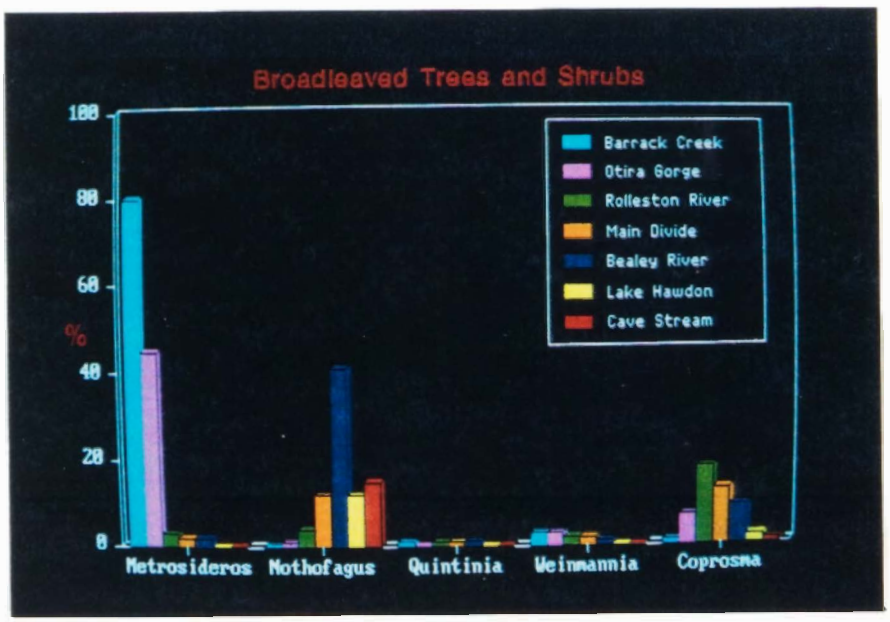
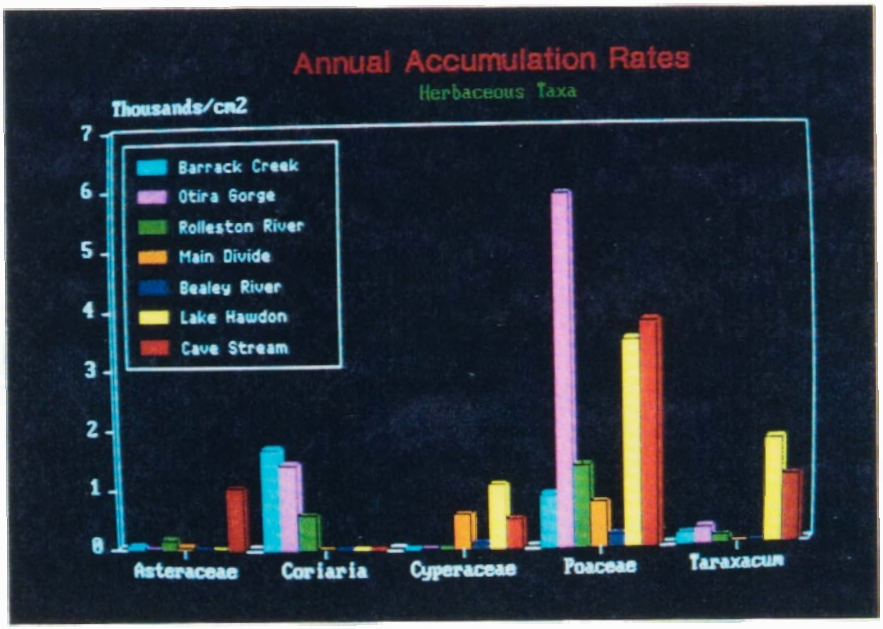


Figure 3.6 Comparison between (a) pollen accumulation rates and (b) percentage values. Major trees and shrub only.

a



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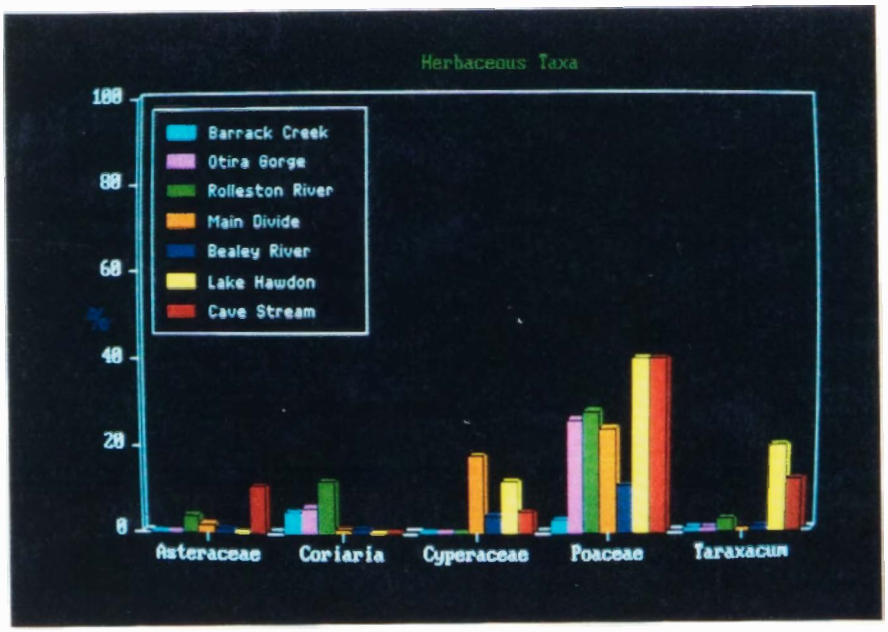


Figure 3.7 Comparison between (a) pollen accumulation rates and (b) percentage values. Major herbaceous taxa only.

For the herbaceous taxa (Figure 3.7)

1. Asteraceae has the same trend in both methods.

2. For *Coriaria* the trend is reversed for the first three sites.

3. Cyperaceae show the same pattern in both methods except at the Main Divide site which has a similar PAR as for Cave Stream, but has the higher percentage.

4. Poaceae percentage is highest at Lake Hawdon and Cave Stream despite a higher accumulation rate at Otira Gorge. The percentage of Poaceae at Otira Gorge, Rolleston River, and Main Divide is similar despite very different accumulation rates.

5. Taraxacum has a similar trend in both the PAR and the percentage values.

3.6.3 Results of Numerical Analysis

The pollen data for the individual traps (Table 3.3) ranged from trace amounts to several thousand cm^{-2}. The data were log transformed but not standardised prior to using numerical methods. The log transformation was performed to compress the upper limits and reduce the importance of larger values over smaller values (Digby and Kempton 1987), so that no single species would assume excessive weight (Sneath and Sokal 1973). The data were not standardised as this would remove real differences (Digby and Kempton 1987) causing drastic weighting of the rarest type or little-varying pollen types at the expense of common or variable ones (Prentice 1980).

Unless otherwise stated all PCAs and CAs were performed using SAS version 6 on an Unisys personal computer. PCA and CA were performed using a covariance matrix of all terrestrial pollen and spores that occurred in at least one site in any season. The covariance matrix was used, because otherwise it would have been necessary to either standardise the data or remove the rare species prior to using a correlation matrix (Sneath and Sokal 1973; Birks and Gordon 1985).

Results of PCA

The principal components analysis results (Figure 3.8) suggest a major separation of the flowering and redeposition season on the first axis (47.9% of the total variance). The second component (20.9% of the variance) shows a gradient between Westland sites (low negative scores) and the open grassland sites in Canterbury (high positive scores). The Main Divide and Bealey River occupy intermediate positions on the second axis. This reflects the change in species from Westland to Canterbury with high accumulation rates of *Metrosideros*, *Quintinia* and *Weinmannia* in Westland

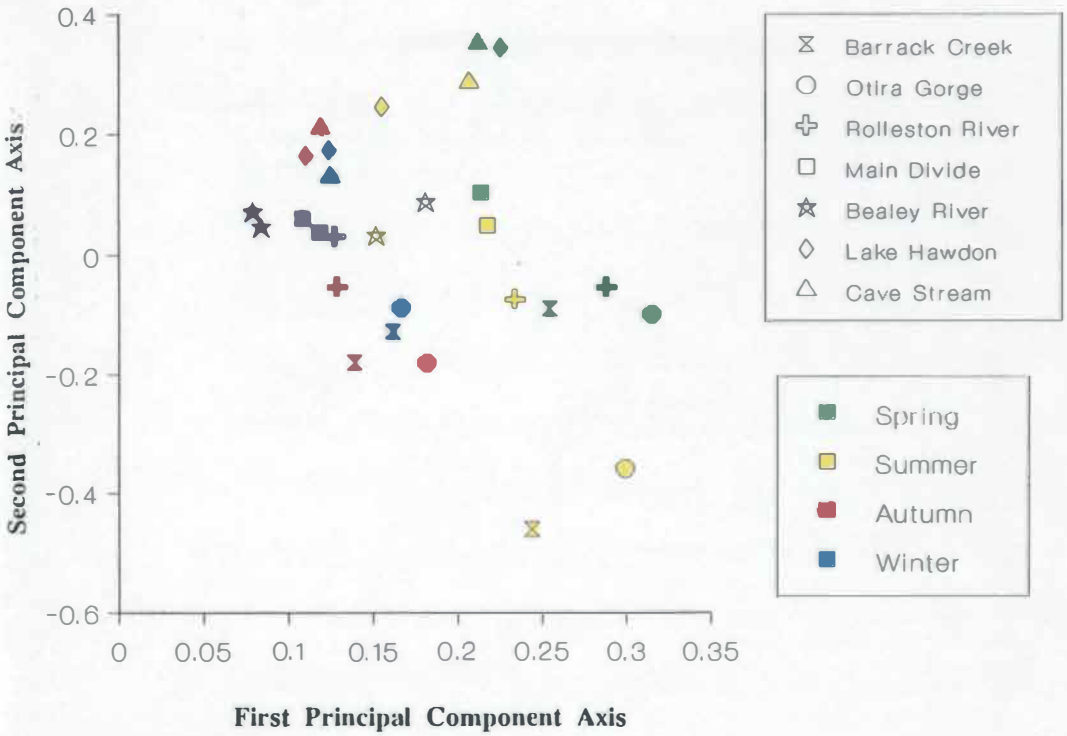


Figure 3.8 Principal Components Analysis of the seasonal accumulation rates (cm^{-2}), at the seven sampling sites.

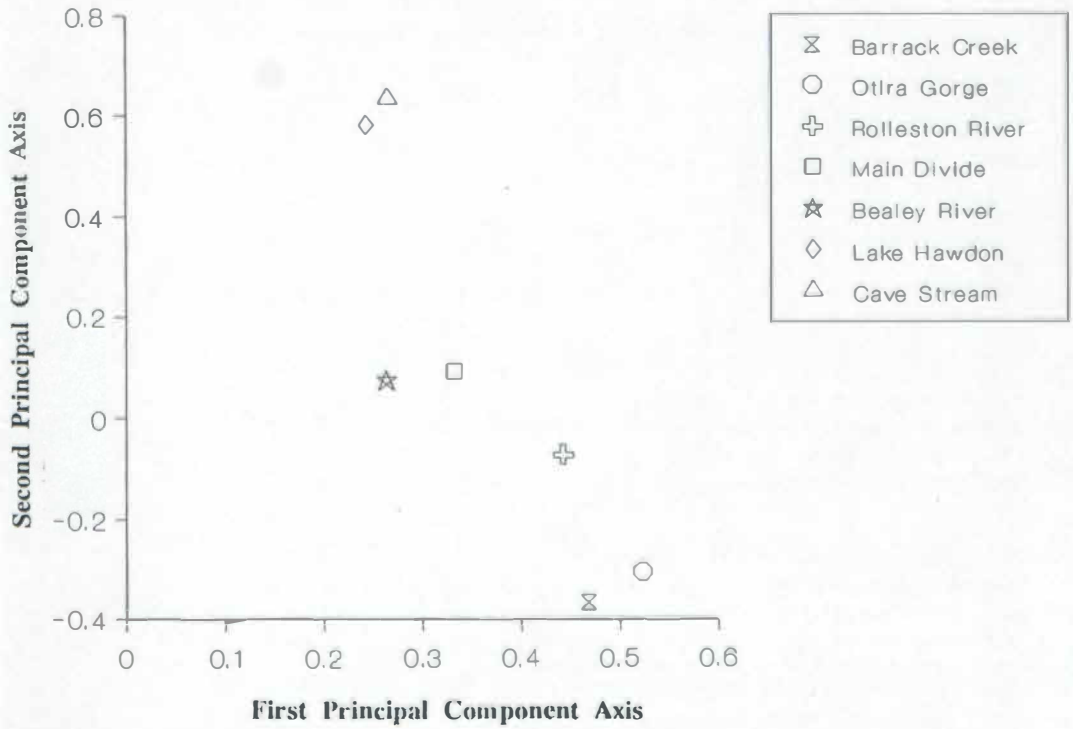
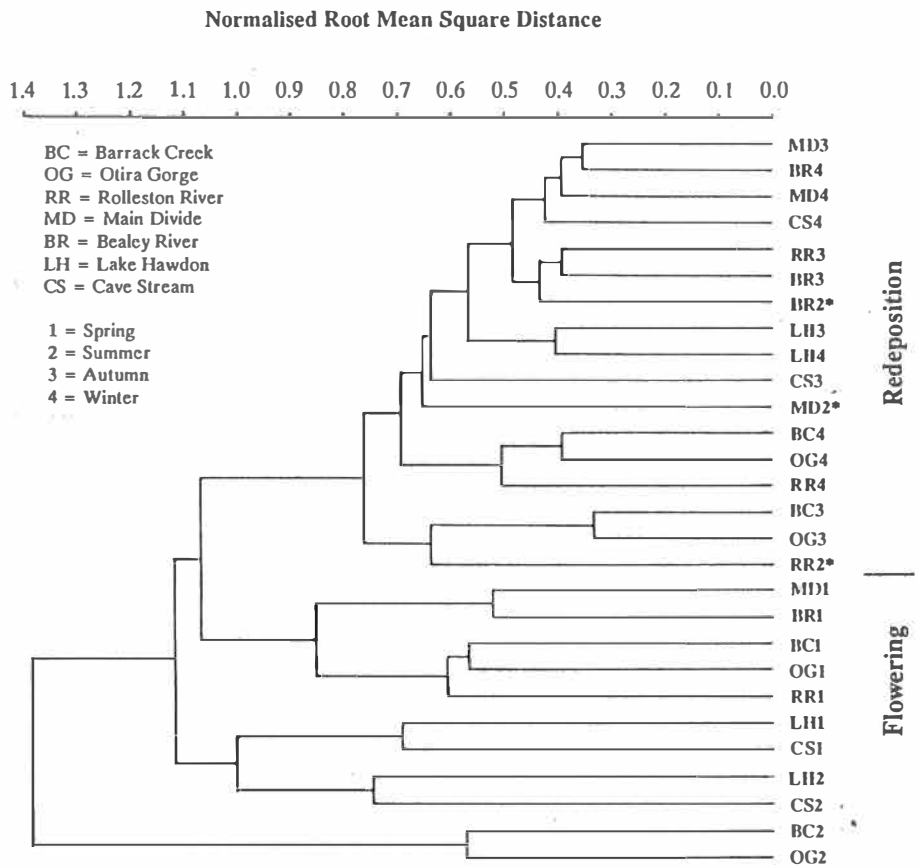


Figure 3.9 Plot of the log transformed total annual accumulation rates (cm^{-2}) for the seven locations on the first and second principal component axes.

(a) Group average



(b) Single linkage

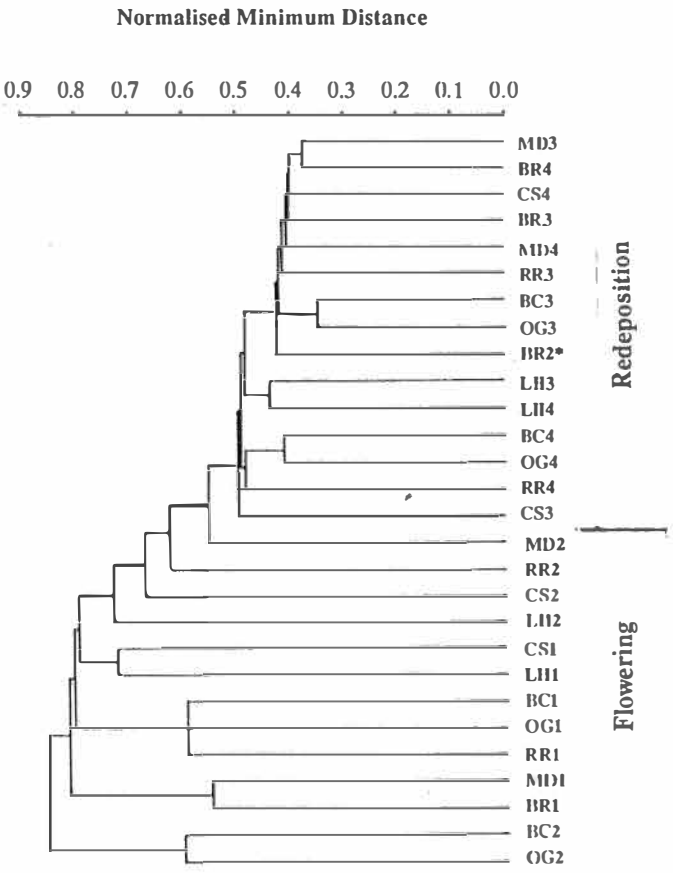


Figure 3.10 Dendrogram showing the results of the cluster analysis of the log transformed seasonal pollen accumulation rates (cm^{-2}) per site. (a) Group average linkage; (b) Single linkage.

and high rates for *Nothofagus*, Asteraceae, Cyperaceae and Poaceae in Canterbury. This pattern is also shown in the PCA results of the annual accumulation rates (Figure 3.9).

Results of Cluster Analyses

The results of the cluster analyses are presented as dendrograms. The group average linkage (Figure 3.10a) shows that the separation of the above two major groups is clearer with group average linkage, even though three traps: BR2, RR2 and MD2, group with the autumn/winter cluster. Single linkage (Figure 3.10b) shows there is much chaining, but a major separation of redeposition from the flowering season is visible. This separation includes all autumn and winter traps and one summer data point (BR2). Two other summer traps (RR2 and MD2) join on to the redeposition group. This may be due to lower accumulation rate at these three sites during the summer, and thus less variation in the pollen accumulation. The remaining traps from spring and summer show a high level of chaining, but do not form any major grouping.

The two numerical methods both suggest a major separation of the two deposition seasons, though there is a some overlap between the seasons.

3.7 DISCUSSION

The earliest pollen trapping studies in New Zealand were concerned with atmospheric allergy studies (Clark 1951; Licitis 1953). These two studies used impact slides in cities only. There have been other pollen trapping studies, using Tauber traps (McKeller 1973; Myers 1973) but these were mostly concerned with *Nothofagus* pollen dispersal. Due to the different trapping methods and differences in the presentation of the results, they are not comparable with the results of this study.

Pollen trapping normally requires the collection of data over a number of years to smooth out the year to year vagaries of pollen production, weather patterns, topography *etc*. Despite these limitations, the single year's trapping results from this study should give some indication of the dispersal of those species which flowered during the year 1987-88 and the general patterns to be expected.

The results demonstrate clearly that there is a main flowering season (spring and summer) and a redeposition period (autumn and winter). Most of the pollen is deposited during the main flowering season with redeposition accounting for only 3-10% of the annual deposition. Redeposition originates from the washing of pollen from the branches and leaves by autumn and winter storms.

Tauber (1967), investigating the mode of pollen transfer in a deciduous forest site, found that more than half of the AP grains were collected in the redeposition period and that the redeposited pollen was associated with rain drops. Other overseas studies (Berglund 1973; Hicks 1985) showed, however, that redeposition was not a major component of the annual pollen deposition.

One of the unexpected results was the low amounts of podocarp pollen found in the traps. Most of the podocarp species have marked periodicity in flowering (Beveridge 1964). The summer of 1989 was a good seed year for *Dacrydium cupressinum* in Westland (Dr. D. Norton pers comm), which implies a good pollen production the previous year. *Prumnopitys* produces pollen annually (Beveridge 1979). The low podocarp values may be due to the inability of the trap to either retain this type of pollen, or that it was not released during the processing of the trapping medium (Hicks and Hyvarinen 1986). Another possibility may be due to dispersal of the pollen. Moar and Myers (1978) recorded different values for *Pinus* between two sample locations in one year, and high frequencies at both sites the following year. Both *Halocarpus* and *Podocarpus totara* type were missing from the pollen deposition. It is possible that these two genera did not flower during the sampling year. This is further supported in that *Podocarpus nivalis* had ripe fruit in January 1990 which implies that the release of pollen was in the spring of 1988 and not 1987.

Metrosideros had the highest accumulation rate for any taxa but is very local and the pollen does not appear to be well dispersed. The high rate may be partly a reflection of the procedure used to determine the amount of pollen in the trap. The number of exotic counted from the summer traps from Barrack Creek and Otira Gorge was less than 100 (means of 21 and 45 respectively) even after the pollen count was doubled. However, as is discussed in Chapter 4, the anomaly probably results from deposition in bee faeces.

Fallout of *Nothofagus fusca* type increases away from the forest site and this has been observed for other wind pollinated taxa (Davis *et al.* 1973) This is probably due to the fact that within the forest only the trees immediately around the site contribute pollen, whereas in the open sites (Lake Hawdon and Cave Stream) larger numbers of upwind trees are represented. *Nothofagus menziesii* pollen was absent, though it flowers annually (Godley 1979). However, there is very little *N. menziesii* forest upwind of the trap sites.

At several sites *Coprosma* appears to have a high redeposition in the 'winter'. This may be due to *Coprosma* flowering in September (spring).

Poaceae shows high accumulation rates in the modified grassland sites which reflects the affect of the introduced grasses in those areas. The Main Divide has more native grasses which have a lower pollen production and they do not flower annually e.g. approximately three year flowering intervals (Godley 1979).

The use of 95% confidence limits and the null hypothesis allows one to determine whether the variation observed between two traps result from chance variability that is expected in samples or from a real difference. This information is not normally available (e.g. Hicks 1985; Cundill 1986).

It is not possible to make any major definitive conclusions with only one year of pollen trapping due to all the processes involved in the deposition of pollen, but the following trends were observed:

1. *Metrosideros* has the highest PAR of any of the studied taxa, but it declines rapidly over a few hundred metres;
2. There is a greater PAR for beech in the grassland sites then in the forest;
3. Poaceae has a high PAR and is the dominant pollen produced in the grassland sites.
4. The local taxa have high PAR, and are the major contributors to the redeposition.
5. Redeposition is not a major component of the annual pollen deposition.

CHAPTER 4
SURFACE TRANSECT

4.1 INTRODUCTION

This chapter describes the surface transect study. The aims were to:

1. Examine the relationship between the deposition of modern pollen and the vegetation that produced it;

2. Attempt to identify regional vegetation types in terms of their pollen spectra and from this to identify the contribution of different source areas to the pollen spectra across the transect.

This involved the collection of moss polsters (mostly *Sphagnum* spp.). The use of moss polsters is a well-established practice (Wright 1967; Birks and Birks 1980; Birks and Gordon 1985) and is preferred in this study to the alternative, lake sediments, for the following reasons:

1. Many of the plant taxa are either entomophilous or ornithophilous (especially those in Westland forests) and the moss polsters are more likely to collect the full range of pollen types (Caseldine 1989);

2. The pollen in lake sediments, particularly a lake with an inlet, may come from sites at a considerable distance (Peck 1973; Bonny 1978);

3. Pollen spectra from lake sediments varies according to the sediment type (Davis *et al.* 1969; Birks 1970; Davis *et al.* 1973; Pocknall 1980) whereas in polsters, the relative proportions of pollen types are similar regardless of moss species used (Carroll 1943);

4. Only aerial transport of pollen is involved with the moss polster (Janssen 1981), whereas in lake sediments inwashing of pollen may cause over-representation of some taxa (Pocknall 1980) and transport by water may lead to incorporation of pollen not part of the regional aerial pollen spectra (Janssen 1981);

5. Moss polsters are easily collected and a great variety of locations can be utilised, as mosses are abundantly present in the land vegetation;

6. To have samples comparable to those from the pollen traps and the peat monoliths.

4.2 LOCATION OF SAMPLE SITES.

Forty moss polsters (*Sphagnum* and other bryophytes) and three lichen samples were collected along a transect from Kumara Junction in Westland, across the Main Divide at Arthur's

Pass to Porters Pass in Canterbury (see Table 2.1, Figure 2.1 and Figure 2.8). Moss samples from similar vegetation types from different locations were also collected to determine the variability of the pollen content.

4.3 SELECTION OF SURFACE SAMPLES

To obtain a representative sample and to minimise some of the effect of pollen input from local species, at least four to six subsamples were collected at random at each site and combined into one sample (Janssen 1981). To reduce the possibility of differential filtration of pollen by the moss polster, the whole thickness of living moss was removed (Crowder and Cuddy 1973). The moss polster should yield a pollen spectrum representative of the pollen deposition for one to several years. At most sites, samples were collected, where possible, from open bogs and not from beneath the forest canopy. The samples were transported to the laboratory in sealed plastic bags.

In areas where suitable moss polsters could not be found, lichen samples were collected from the top of fence posts (sites D & E) by removal of the entire piece of lichen. Two samples from (Site A) in Westland were collected to compare the pollen spectra from a moss polster (A1) and a lichen (A2) as Carroll (1943) found lichens to be less effective than moss polsters. However, McKellar (1973) and Moar & Myers (1978) found comparable results for mosses and lichens.

4.4 METHOD OF POLLEN PREPARATION

The method most commonly used to remove the cellulose from moss leaves, rootlets, and other structures, is the acetolysis method, introduced by Erdtman in 1934 (Faegri & Iversen 1964).

For pollen analysis about 40 cc of moss or lichen were removed from the plastic bags and placed directly into 50 ml boiling tubes. They were treated with 5% sodium hydroxide and placed into a boiling water bath for 10 minutes during which time the samples were stirred to release trapped pollen grains and spores. The samples were then sieved through 0.01 mm mesh and rinsed with distilled water. The residue was treated with 40% hydrofluoric acid for 10 minutes in a boiling water bath to remove silicates. The standard method was then used to acetolyse the pollen (Faegri and Iversen 1964). The final residue was stained with 1% aqueous safranin. One drop of residue was added to four drops of melted glycerine jelly and thoroughly mixed on the slide, prior to the addition of a cover slip. Pollen counting and identification were as outlined in Chapter 3 section 3.4.

4.5 ADDITION OF EXOTIC SPORES TO SURFACE SAMPLES

When this project began it was intended to primarily use percentage data. Later, 'absolute' counts for some of the sites were carried out using the method of Stockmarr (1971):

1. To see if the trends that were evident in the pollen trap data were reflected in the moss polsters from the same locations; and

2. To gain some insight as to whether the upslope transport involved:

(a) an increase in the accumulation of pollen to the Main Divide from the lowland and montane slopes to the west;

(b) relatively low pollen production and deposition of pollen from the local taxa.

It would have been desirable to obtain additional information of this kind regarding the deposition of pollen along the entire transect but time did not permit redoing all 42 sites. The 14 sites selected (Table 4.1) were those on and near the Main Divide (H-N), the other sites where the pollen traps were located (AF, AL), two additional sites in the beech forest (sites Q and R), two sites from Westland; near (site B) and in (site C) the podocarp/broadleaved forest and the easternmost location (site AP). It was not necessary to recollect samples as there was a sufficient amount of moss remaining from the original collection. Samples of moss were oven dried at 80^{0}C for 8 hours. Two *Lycopodium* tablets containing 10850 $\pm$ 200 spores per tablet were added to one gram of dry material, processed and analysed as before.

Table 4.1 The 14 surface samples to which two *Lycopodium* tablets were added. For location and vegetation descriptions see Chapter 2 Section 2.3.

Location Name	Site	Moss collected
Kumara	B	*Sphagnum falcatulum*
Loop Line Road	C	*Sphagnum cristatum*
Barrack Creek	H	*Racomitrium* sp.
Otira Gorge	I	*Racomitrium* sp.
Rolleston River	J	*Hypnum* sp.
Lower Bog, Main Divide	K	*Sphagnum cristatum*
Upper Bog, Main Divide	L	*Sphagnum falcatulum*
Dobson Memorial	M	*Sphagnum cristatum*
Bealey River	N	*Sphagnum falcatulum*
Quarry Bog	Q	*Sphagnum cristatum*
Bealey Forest	R	*Sphagnum cristatum*
Lake Hawdon	AF	*Bryum* sp.
Cave Stream	AL	*Sphagnum falcatulum*
Porters Pass	AP	*Sphagnum cristatum*

4.6 STATISTICAL ANALYSIS OF SURFACE SAMPLE DATA

4.6.1 95% Confidence Intervals

Usually only one sample was done per site, due to the amount of work involved in processing and counting pollen grains. How reliable and repeatable are the results?

Mosimann (1965) showed that in pollen analysis the counts of a taxon follow a binomial distribution when counting to a fixed total number of pollen and spores. He provides equations to estimate the 95% confidence limits for those counts.

The limits of the sampling error of any taxon is defined by the standard variation of the binomial distribution, which is dependent on the value of the observed taxon and on the total number of grains counted (Birks and Gordon 1985).

The confidence interval is a random interval with specified probability that it will contain the unknown true value of the taxon. The value of a taxon obtained may or may not be the true value for that taxon, but we are 95% confident that the interval does contain the true value. For a more detailed discussion on the use and the methodology of confidence intervals in pollen analysis, see Maher (1981) and Birks and Gordon (1985).

The 95% confidence intervals for percentage data and the 'absolute' pollen counts, assume a binomial distribution and that the data are from a normal distribution. As far as is known this assumption is correct.

4.6.2 Principal Components Analysis

Principal Components Analysis was performed on the unstandardised pollen percentage data. The first data set contained all taxa ('all') which obtained values of 1% or more in at least one location. The second data set had the wet site taxa and ferns deleted ('nwf') from the pollen sum and the percentages recalculated. A third analysis was done using only the four major taxa (*Dacrydium cupressinum*, *Metrosideros*, *Nothofagus fusca* type, and Poaceae).

From the results of the exotic marker study, two data sets were analysed. One using log transformed 'absolute' values and a second using unstandardised percentage data.

4.6.3 Cluster Analysis

Both group average linkage and single linkage were performed on the 'all' and 'nwf' data sets. It is expected that the results of the single linkage will contain a moderate amount of chaining due to the continuous nature of the variation within the surface transect.

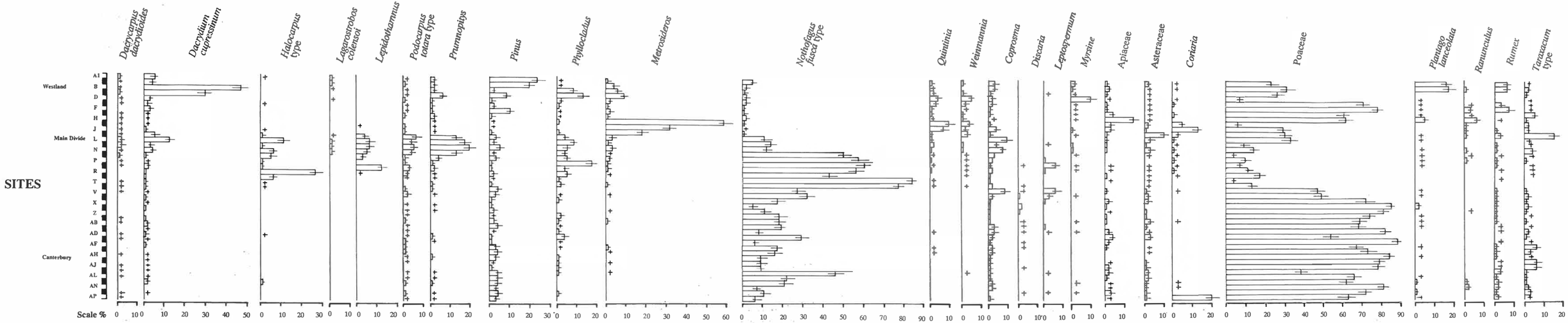


Figure 4.1 Pollen profile based on a pollen sum containing all terrestrial taxa with values of 1% or more in at least one location. Excludes wet site taxa and ferns. (+ = less than 1%). Taxa not shown are Cupressaceae, *Aristotelia, Ascarian, Hoheria, Muehlenbeckia, Nothofagus menziesii, Schefflera, Epacridaceae, Bulbinella,* Papilionaceae, *Phormium* and indigenous *Plantago* (see Appendix B).

4.7 RESULTS OF SURFACE TRANSECT STUDY

4.7.1 Percentage Data

The pollen percentage results of the samples from the surface transect are shown in Figure 4.1. The pollen sum is based on all terrestrial taxa with values of at least 1% in one or more samples. Excluded are the wet site taxa (Centrolepidaceae, Cyperaceae, *Donatia, Haloragis*, and *Typha*) and ferns. The features of the surface transect are:

1. *Dacrycarpus dacrydioides* has its highest value (2%) at sites L and M on the Main Divide, 1% at sites A and B and trace amounts at the remaining sites;

2. *Dacrydium cupressinum* pollen percentage is highest at sites B (46%) and C (29%) and then at site L (12%) on the Main Divide;

3. *Halocarpus* has its highest value at site R (26%) and is important at sites L (11%), N (6%), O (5%) and S(6%);

4. *Lagarostrobos colensoi* is highest at site A (1%) in Westland, then sites L, M and N (all at 1%) on and near the Main Divide;

5. *Lepidothamnus* highest value is at site Q (12%) with minor peaks at sites K to O (3-6%);

6. *Podocarpus totara* has low values across most of the transect. A small peak occurs at sites K to N (4-6%);

7. The highest percent values for *Prumnopitys* are at sites K to N (13-19%) on the Main Divide;

8. *Pinus* highest values are at site A (19-23%) and site F (10%). It is generally present along the transect at 2-4%;

9. *Phyllocladus* highest percentage values are at sites C (13%) and P (17%) with minor peaks at sites K-R (4-8%);

10. *Metrosideros* is the dominant pollen at site H (59%). It is also important at sites I (32%) and J (18%), with minor peaks at sites B (6%) and C (9%) and declines rapidly eastwards;

11. *Nothofagus fusca* type pollen has low values (1-5%) at all the Westland sites. It dominates at sites N-T (43-84%), all surrounded by beech forest. Peaks occur at site AK (46%) and moderate values at sites U (27%), V (32%), AD (29%), AL (22%) and AM (21%). The remaining sites have values of 5-19%;

12. *Quintinia* has its highest values at sites H (10%) and I (7%). All remaining Westland sites have low values (1-4%) and it is unimportant in the Canterbury sites;

13. *Weinmannia* has its highest values at sites B (5%) and H (4%) and low values in the other Westland sites. Like *Quintinia* it is unimportant in Canterbury;

14. *Coprosma* main peaks are at sites K (9%), M (7%) and U (8%), with 1-2% values at all the remaining sites;

15. Only at site X does *Discaria* reach any significant value (2%). None occurs in Westland and only trace amounts at some of the sites in Canterbury;

16. *Leptospermum* has small peaks at sites P (6%), U (6%), and V (3%);

17. The only peak for *Myrsine* is at site C (10%);

18. Apiaceae has its largest value at site G (14%), with low values along the transect;

19. Asteraceae peaks at site J (10%), with low values and trace amounts along the rest of the transect;

20. For *Coriaria*, the main sites are I (13%) and AP (20%). Minor peaks occur at H (5%), J (3%) and it is unimportant eastwards;

21. At most sites in both Westland and Canterbury, grasses are dominant. Grass pollen is also abundant at the Main Divide sites, but is much less important at sites closely surrounded by forest;

22. *Plantago lanceolata* has its main peak at site A (17%), a minor peak at G (5%) and is found in trace amounts along the remaining transect;

23. The greatest peak for *Ranunculus* is at site G (6%);

24. Only at sites A (6%), E (7%) does *Rumex* reach any significant value with trace amounts at all the sites to the east;

25. *Taraxacum* type has its highest value at site J (15%). Minor peaks occur at sites F (5%), AF (6%), AI (6%) and AJ (6%) and trace amounts along the transect.

Though not used to calculate the pollen sum used in the diagram, the wet site taxa which had high pollen counts (out of a total of 700) are Centrolepidaceae at site L (124 grains); Cyperaceae sites K (234), O (193), R (102), V (114), AF (94), AG (112), AJ 108) and *Haloragis* sites W (293), AB (105), AG (151) (see Appendix A).

Those taxa which occurred at 1% in at least one site or more were used in the calculation of the pollen sum, but were not included in Figure 4.1. These include Cupressaceae, *Aristotelia*, *Ascarina*, *Hoheria*, *Muehlenbeckia*, *Nothofagus menziesii*, *Schefflera*, Epacridaceae (cf *Dracophyllum*), *Bulbinella*, Papilionaceae, *Phormium* and indigenous *Plantago* (Appendix B).

Besides the pollen types that were not included in the pollen sum (wet site taxa and ferns), are those pollen types which only occurred in trace amounts (less than 1%). These include trees and shrubs *Pseudowintera*, *Fuchsia*, *Hebe*, *Pimelea*, and the herbs *Donatia novae-zelandiae*, *Drosera*, *Gentiana*, *Gunnera* and *Wahlenbergia* (see Appendix A).

4.7.2 Results of P.C.A.

The Principal Components Analysis (PCA) results of the 'all' data set (Figure 4.2.a) depicts a major separation on the first axis (70.9% of the total variance) between forest and grassland sites, with samples from the *Nothofagus* and the podocarp/broadleaved forests having low positive scores (0.01 to 0.1). The samples from the grassland have high positive scores (0.12-0.27). The second component (16.7% of the variance), suggests a gradient between the Westland podocarp/broadleaved forest (low negative scores) and the *Nothofagus* forest in Canterbury (high positive scores). The subalpine sites which receive pollen from both forest types are intermediate between them.

The PCA of the 'nwf' data displays the same trend (Figure 4.2.b). The main difference is a closer grouping of the eastern grassland sites. The PCA of the four major species (Figure 4.2c) depicts more clearly the separation of the sites. The first axis accounts for 72.5 % of the total variance and a further 22.8% occurs on the second axis. The sites with high Poaceae values have high positive scores on the first axis. The beech sites have low negative scores on the first axis and high positive scores on the second axis. The podocarp/broadleaved sites (sites C and H) have low negative scores on both axes. The subalpine sites on the Main Divide (sites K, L and M) are intermediate. The western and eastern scrubland sites are spread out laterally, depending on the values of rimu, rata, beech and grass pollen present.

Thoughout this study, unstandardised pollen percentages were used. An Arc sin square root (ASSR) transformation (Prentice 1983; Larkin 1978) was performed on the 4 taxa data set to see if it improved the analysis (Figure 4.2d). No major difference between the untransformed and the ASSR transformed results is apparent.

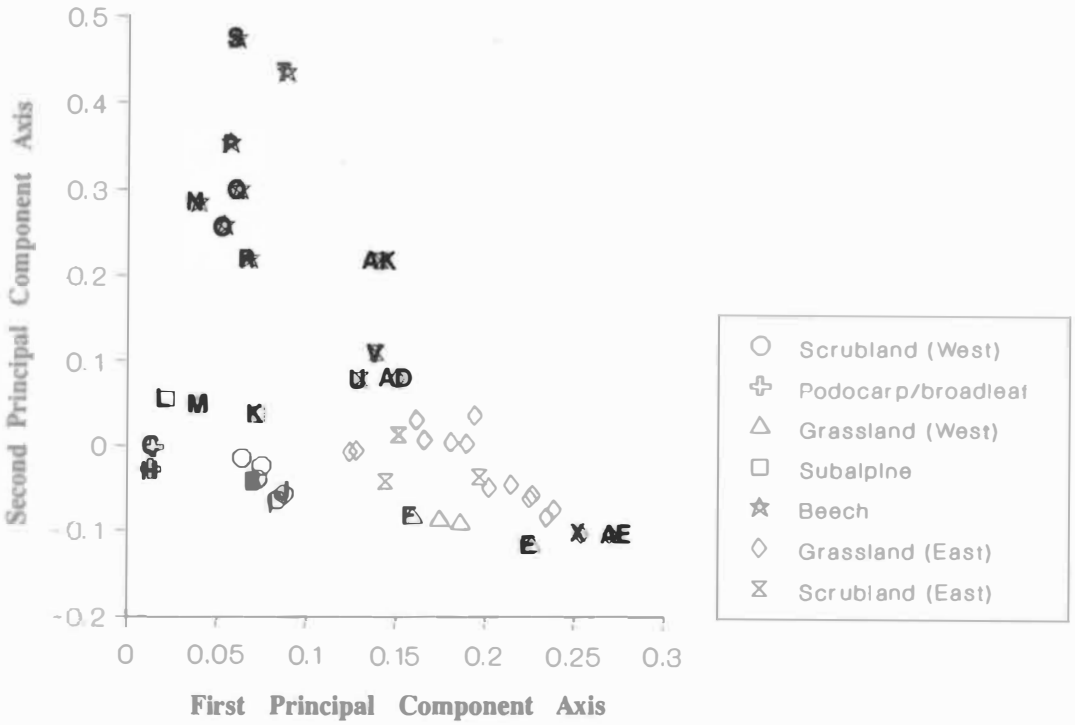


Figure 4.2a Plot of the 43 surface samples on the first and second principal components axes. The vegetation types from which the samples were collected are also shown. This includes wet site taxa and ferns.

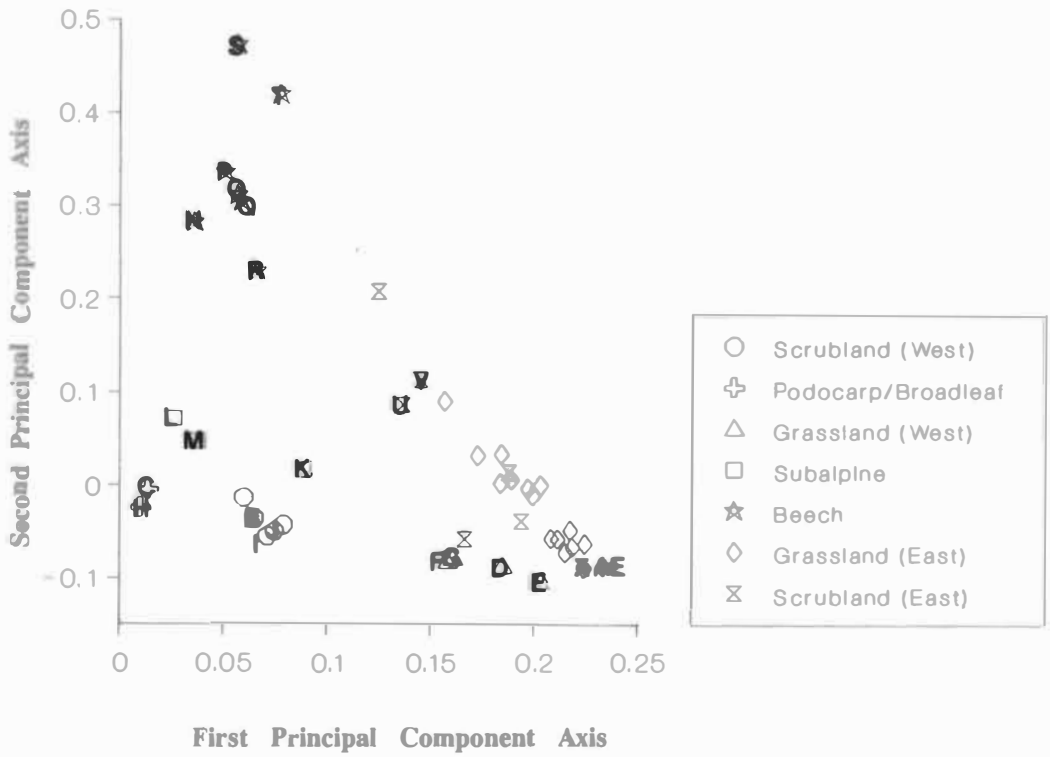


Figure 4.2b Plot of the 43 surface samples on the first and second principal components axes. The vegetation types from which the samples were collected are also shown. This excludes wet site taxa and ferns.

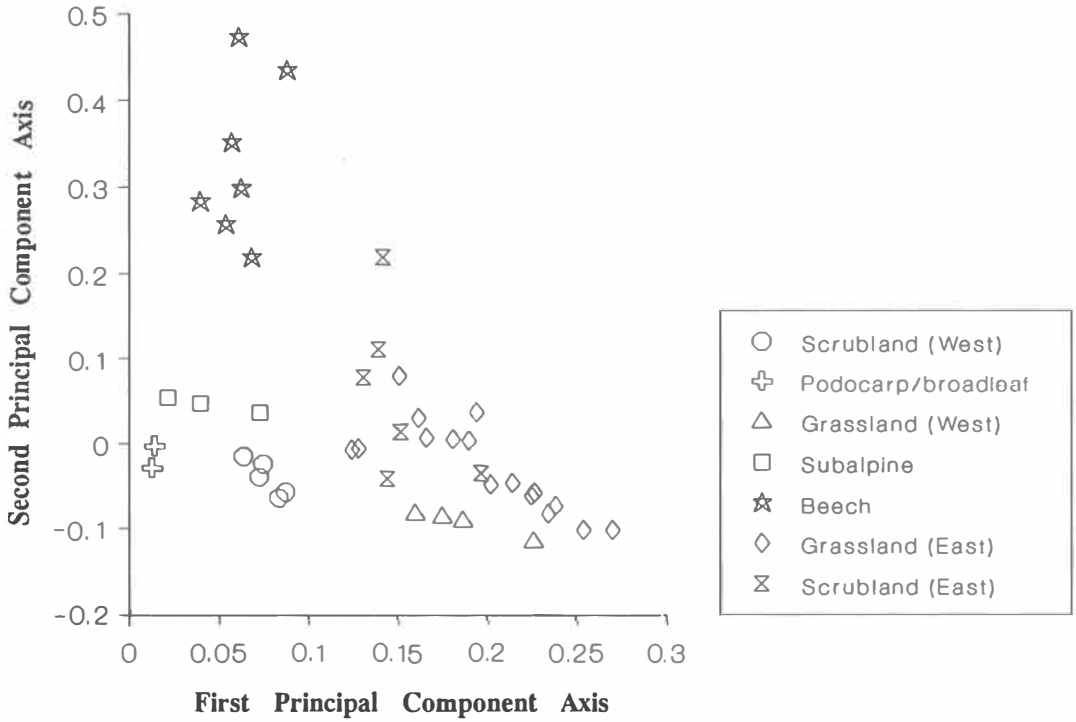


Figure 4.2a Plot of the 43 surface samples on the first and second principal components axes. The vegetation types from which the samples were collected are also shown. This includes wet site taxa and ferns.

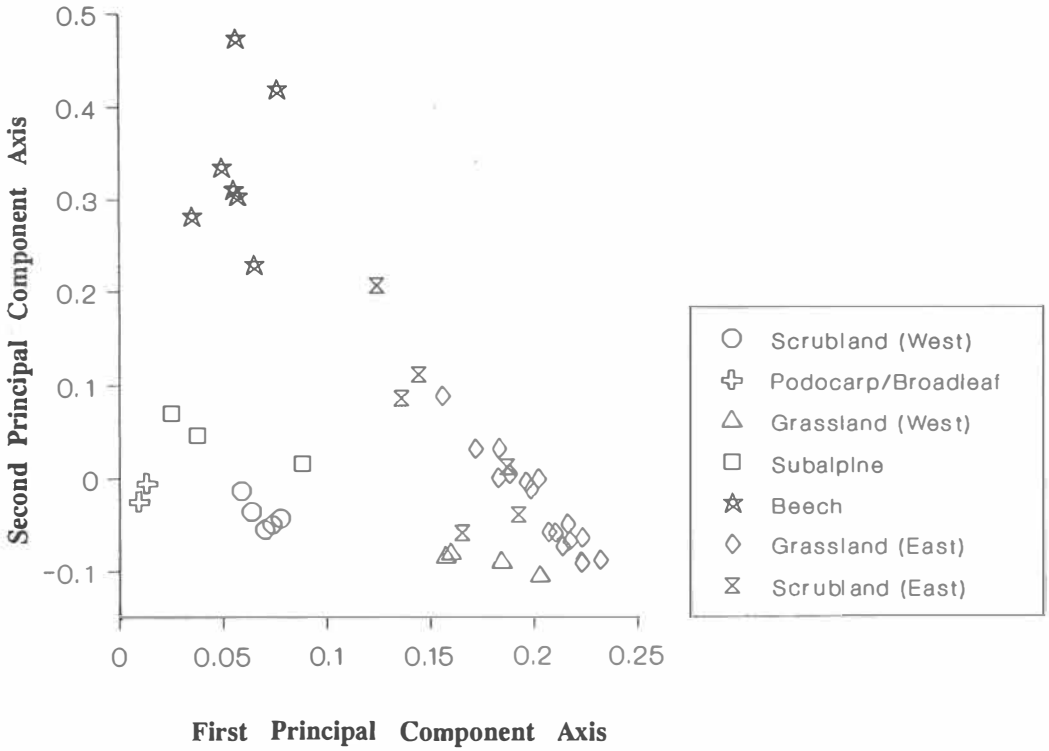


Figure 4.2b Plot of the 43 surface samples on the first and second principal components axes. The vegetation types from which the samples were collected are also shown. This excludes wet site taxa and ferns.

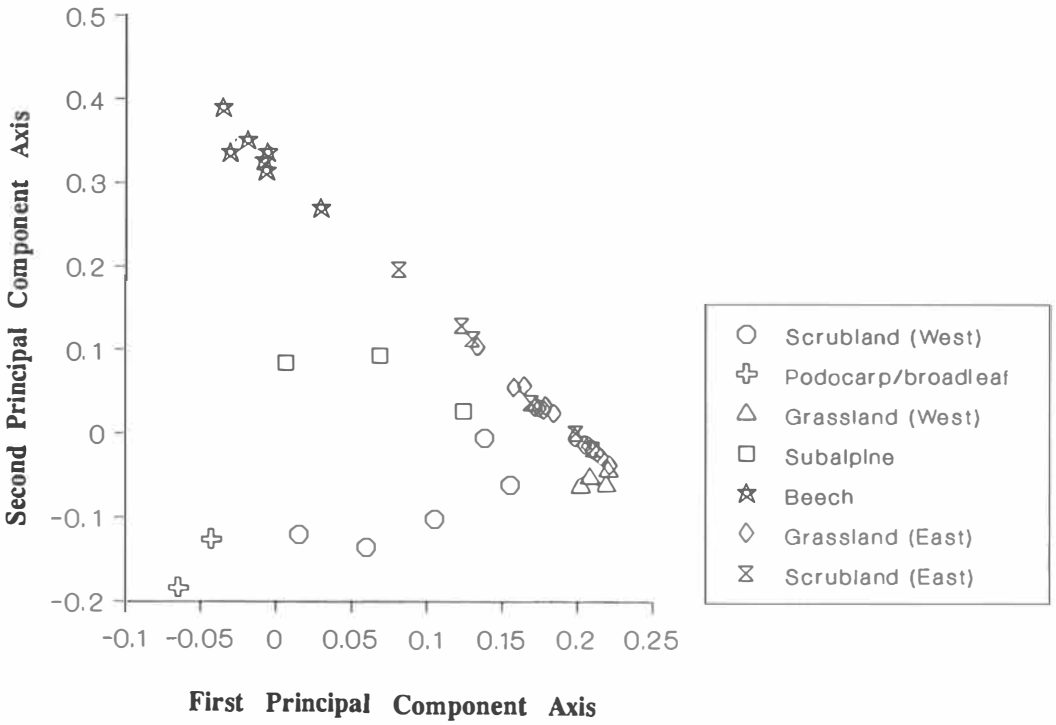


Figure 4.2c Plot of the 43 surface samples on the first and second principal components axes. The vegetation type from which the samples were collected are also shown. This excludes all taxa except *Dacrydium cupressinum*, *Metrosideros*, *Nothofagus fusca* type and Poaceae

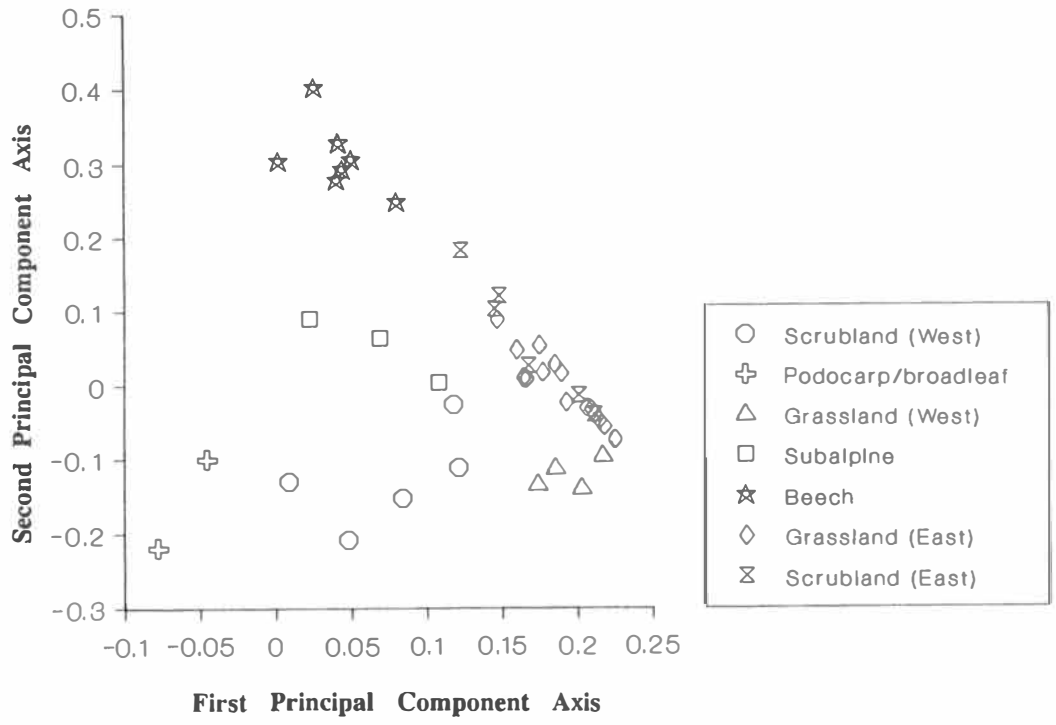


Figure 4.2d Plot of the 43 surface samples on the first and second principal components axes using Arc sin square root transformation. Excludes all taxa except *Dacrydium cupressinum*, *Metrosideros*, *Nothofagus fusca* type and Poaceae. The vegetation type from which the samples were collected are also shown.

4.7.3 Results of Cluster Analyses.

The results of the cluster analyses are presented as dendrograms. The 'all' data set (Figure 4.3) shows the results for a) group average linkage and b) single linkage.

At a normalised root mean square distance of 0.7, group average linkage forms eight clusters as follows:

Cluster 1 includes all of the grassland sites (both west and east) and the eastern scrublands, which contain large pollen percentages of Poaceae.

Cluster 2 is a single site (W) with large pollen percentages of *Haloragis* and Poaceae.

Cluster 3 includes the subalpine sites, the Westland sand dunes and the podocarp/broadleaved forest.

Cluster 4 includes two sites (I and J) both from the western scrubland with high broadleaved tree pollen percentages.

Cluster 5 contains a single site B with high pollen percentages for *Dacrydium cupressinum*.

Cluster 6 includes all of the beech forest sites (N-T).

Cluster 7 is a single site (AK) with high pollen percentages for beech and Poaceae.

Cluster 8 is a single site H for the podocarp/broadleaved forest with large pollen percentages for *Metrosideros*. It is the last site to join the dendrogram.

The dendrograms for the single linkage analysis (Figure 4.3b) register several distinct groups before the onset of chaining.

Group 1 contains most of the grassland sites (west and east).

Group 2 includes two of the eastern scrubland sites.

Group 3 includes all of the beech forest sites.

Group 4 contains all the subalpine sites and the site from the Westland sand dunes.

Group 5 contains two of the western scrubland sites.

Dendrograms for the 'nwf' data are presented for a) group average linkage and b) single linkage (Figure 4.4). At a normalised root mean square distance of 0.7, group average linkage forms 6 clusters.

Cluster 1 includes all of the grassland sites, both western and eastern and all the eastern scrubland sites.

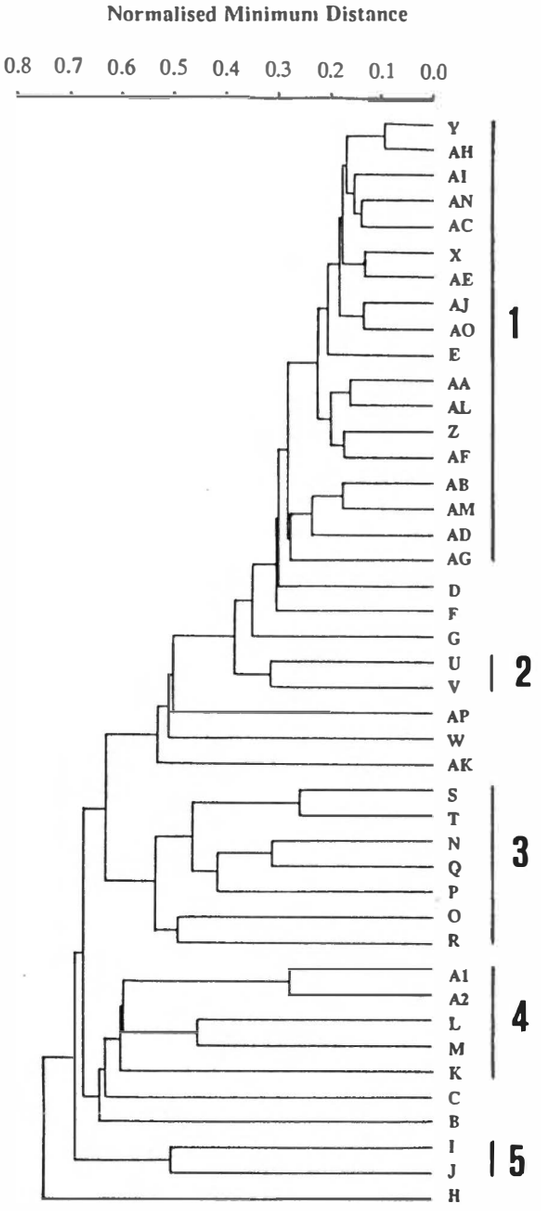


Figure 4.3b Dendrogram showing the results of the 'all' data using cluster analysis based on single linkage method. Five groups are identified.

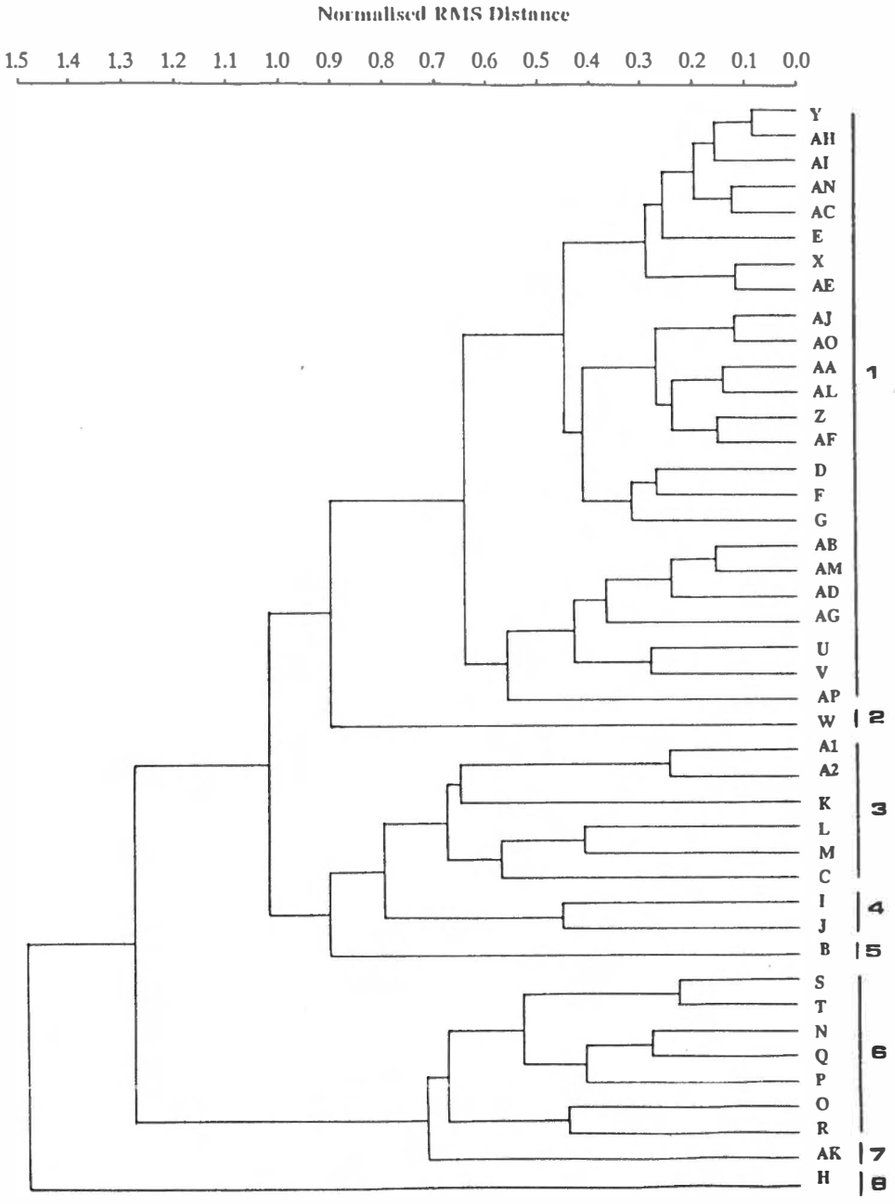


Figure 4.3a Dendrogram showing the results of the 'all' data using cluster analysis based on group average linkage. 8 clusters are identified with at a root mean square (RMS) distance of 0.7.

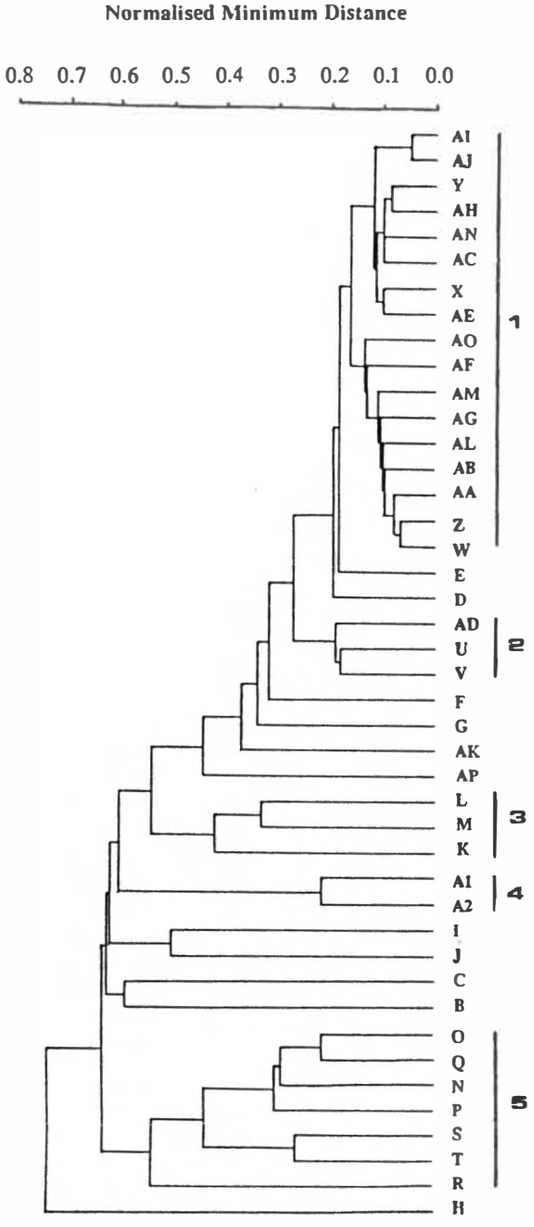


Figure 4.4b Dendrogram showing the results of the 'nwf' data using cluster analysis based on single linkage method. Five groups are identified.

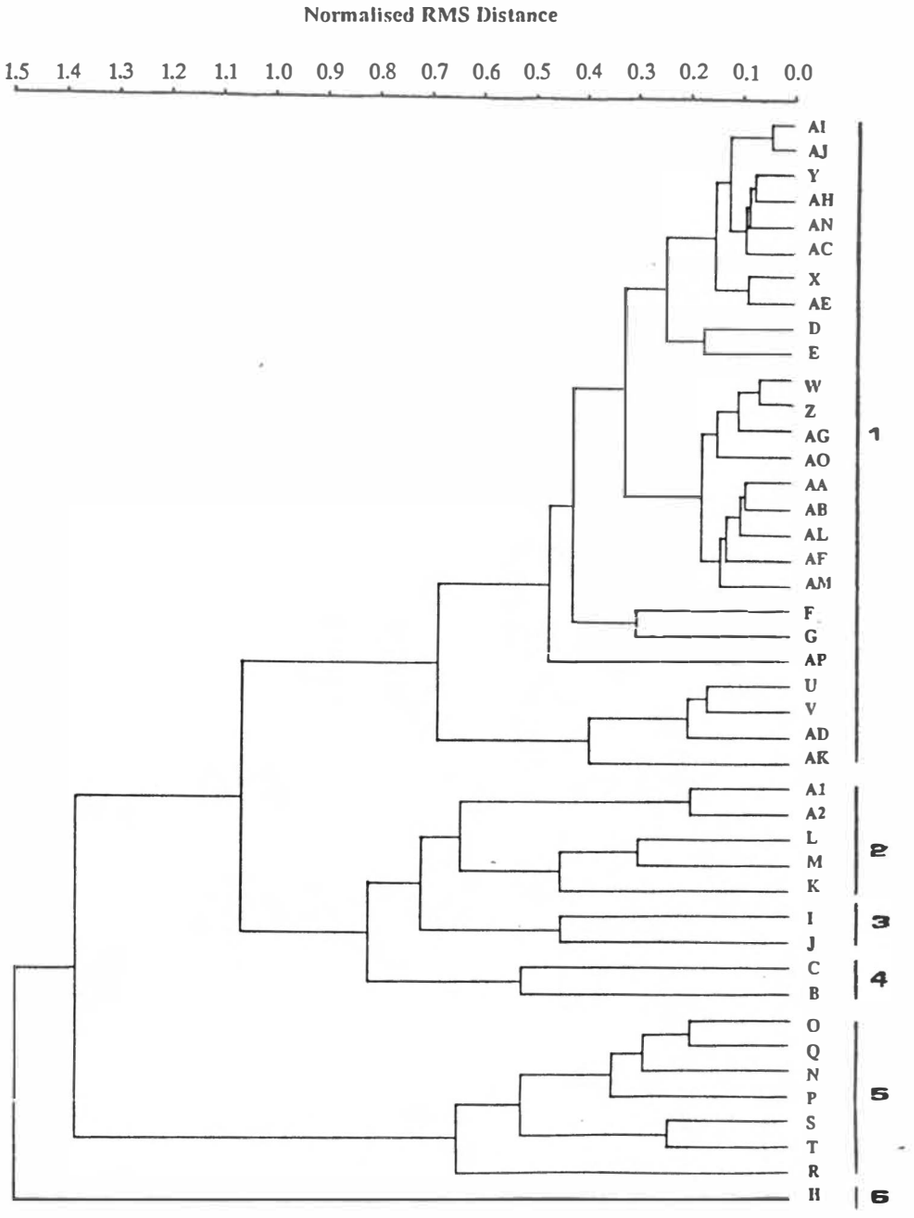


Figure 4.4a Dendrogram showing the results of the 'nwf' data using cluster analysis based on group average linkage. 6 clusters are identified with at a root mean square (RMS) distance of 0.7.

Cluster 2 includes the subalpine sites and the Westland sand dune samples. These sites receive mostly regional pollen.

Cluster 3 includes two sites both from the western scrubland with moderate values of broadleaved tree pollens.

Cluster 4 includes two sites, in which *Dacrydium cupressinum* is the dominant pollen.

Cluster 5 includes all of the beech forest sites N-T.

Cluster 6 is a single site H, which joins the dendrogram last.

The dendrogram of the results using single linkage (Figure 4.4.b) isolates several distinct groups before the onset of chaining.

Group 1 contains most of the eastern grassland/scrubland sites.

Group 2 contains three eastern scrubland/grassland sites.

Group 3 contains the subalpine sites.

Group 4 contains the two samples from the Westland coastal site.

Group 5 contains all the beech forest sites.

The significance of the results is discussed in Section 4.9.1.

4.8 RESULTS OF EXOTIC MARKER STUDY

The results of the 'absolute' counts with 95% confidence intervals are shown in Figure 4.5 (see Appendix C for raw counts). The Y axis is on a log scale to assist in viewing the overall pattern. The null hypothesis (that the difference between the two estimates results simply from chance variability expected in samples with the same true pollen concentration) was tested on the 14 samples. This was done to decide whether the estimated concentration from a sample is too different to have come from the same population. The test for the null hypothesis was performed using a program devised by Dr. L. Maher Jr. (Maher 1981). The results of the individual analyses are displayed in Appendix G. The general features of the pollen concentrations (Figure 4.5) are:

1. *Dacrydium cupressinum* has its highest mean 'absolute' value at Kumara (233740 grains gm^{-1}), 12112 grains at the Upper bog on the Main Divide, and 9521 in the podocarp/broadleaved forest (Loop line road). At all the remaining sites there are less than 7000 grains gm^{-1}.

2. *Podocarpus totara* type has similar values at most sites, declining eastwards;

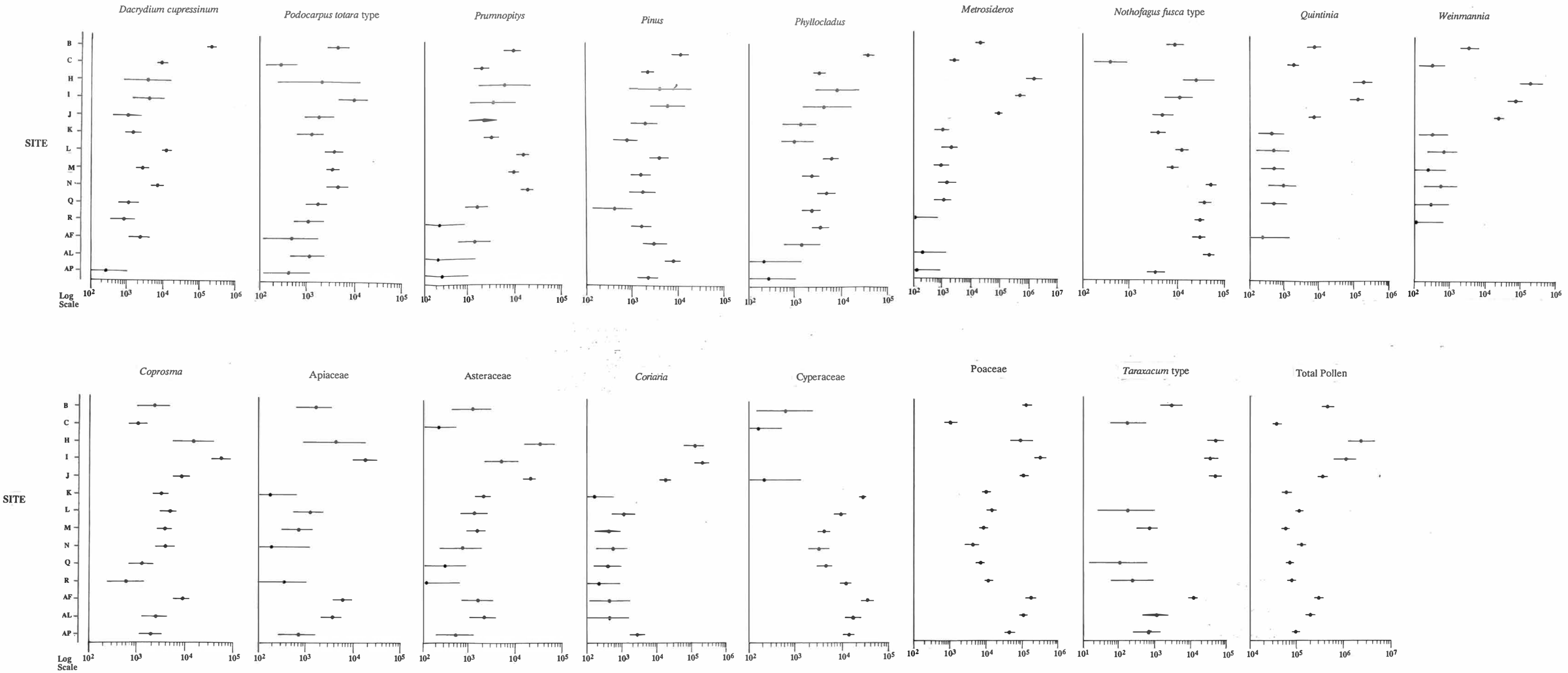


Figure 4.5 'Absolute'values from the 14 surface samples with 95% confidence intervals. Only the main taxa are shown.

3. *Prumnopitys* highest values are at sites L, M and N. Sites at H, I, J and K have similar values. Sites Q and AF have the same value while R, AL and AP have similar low values;

4. *Pinus* has similar values along the transect;

5. *Phyllocladus* has similar values wherever it is present in the local vegetation (Sites C, M-R).

6. At Barrack Creek, *Metrosideros* dominates (1,457,845 grains gm^{-1}) then declines to a third as much (479069) at Otira Gorge 300 m to the east, then 85932 grains at Rolleston River. The only other site to have a significant value of *Metrosideros* is Kumara (20150).

7. *Nothofagus fusca* type has similar values in both the beech forest sites and the eastern grasslands. Bealey River (47740 gm^{-1}) and Cave Stream (44919) have the same value as do Bealey forest (29127) and Lake Hawdon (28856);

8. *Quintinia* has high local values (sites H (187409 gm^{-1}) and I (130200)) declining rapidly over a short distance from the source (site B (7750) and J (7595)). *Quintinia* has a similar low value for sites across the Main Divide and at sites further to the east;

9. *Weinmannia* highest value is at site H ((197273 gm^{-1}) reducing eastwards ((I 80958) (J 25606)); moderate value occur at Kumara where there are a few trees 200 m to the west of the site. Low, even values occur to the east and in the podocarp/broadleaved forest;

10. *Coprosma* has its highest 'absolute' value at site I (50912 gm^{-1}) with similar values across the Main Divide sites (3050-4542);

11. Apiaceae has low values at the Main Divide and beech forest sites. Its highest value is at site I (16692 gm^{-1}) with similar values for sites H, AF and AL;

12. Asteraceae has highly variable values in Westland, but similar values for most of the Canterbury sites;

13. *Coriaria* has similar values at sites H and I where it is present, declining eastwards. All of the Canterbury sites have low but similar values;

14. Cyperaceae has low values at the Westland sites; they are high, but variable, in Canterbury;

15. Poaceae has its highest value at site I (307138 gm^{-1}). At sites B, H, J and AL Poaceae has similar values. The Main Divide and two of the beech forest sites (Q and R) have similar values. Low values occur in the podocarp/broadleaved forest (site C) and the beech forest site N.;

16. *Taraxacum* type has high, but similar values at sites H (47345), I (35054) and J (47306). Variable values occur at the remaining sites;

17. Total pollen per gram is highest at Barrack Creek (2,434,345 gm^{-1}), half as much at Otira Gorge (1,502,308) 300m to the east, then Kumara (496,000), Rolleston River (370,853), Lake Hawdon (307032), Cave Stream (202678), Bealey River (132087), Upper Bog (117752). The remaining sites all have values from 34099 (Loop Line road) to 97281 at the Lower Bog.

The result of the Principal Components Analysis of the log transformed 'absolute' values is shown in Figure 4.6a. The first axis, which accounts for 45.1% of the total variance, depicts a separation between those sites which receive predominantly podocarp pollen (high positive scores 3.1 - 3.4) and those with mainly Poaceae pollen (low positive scores 0.20 - 0.24). The second axis (19.6% of the total variance) depicts a separation between those sites with high *Nothofagus fusca* type pollen (low negative score (-0.20) and those with mostly broadleaved pollen (predominantly *Metrosideros* with *Quintinia*, and *Weinmannia*) (high positive scores 0.50 - 0.60).

Figure 4.6b displays the result of the Principal Components Analysis of the unstandardised percentage data (Appendix F). The first axis (44.4% of the total variance) depicts a separation between grassland sites (high positive scores 0.48 - 0.50) and the forest and scrubland sites. The second axis, accounting for an additional 20% of the total variance, depicts a separation between beech forest sites (low negative scores) and broadleaved forest sites. Those sites which have pollen from the various vegetation types are intermediate.

4.9 ANALYSIS AND DISCUSSION

The amount of pollen recovered from a site is controlled by several interacting factors. These are:

1. Pollen production, which is related to the mode of pollination. The anemophilous taxa are usually high pollen producers, while the entomophilous taxa are low pollen producers. The total amount of pollen produced by a particular taxon in an area depends on the number of individuals and the frequency of flowering which is related to genetic, physiological, climatic and ecological conditions.

2. Pollen liberation is highly seasonal. The results of the seasonal accumulation rates (Chapter 3) demonstrate the seasonal pattern of pollen liberaton in the study area.

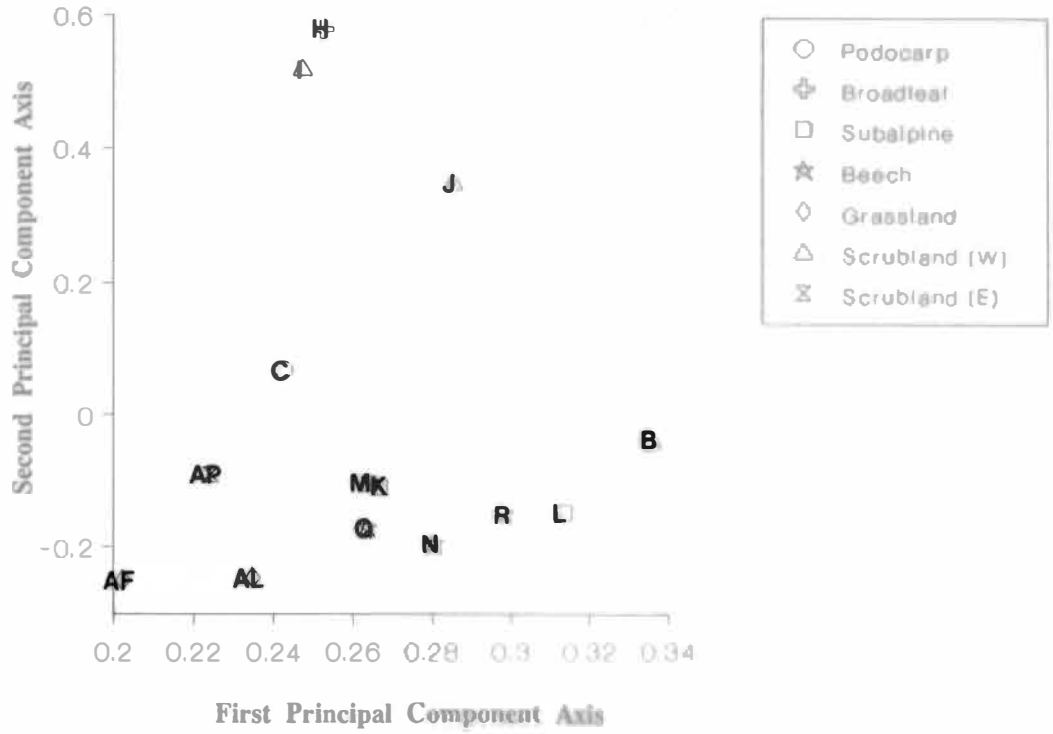


Figure 4.6a Plot of the 14 surface samples on the first and second principal components axes using log transformed 'absolute' values. The vegetation type from which the samples were collected are also shown.

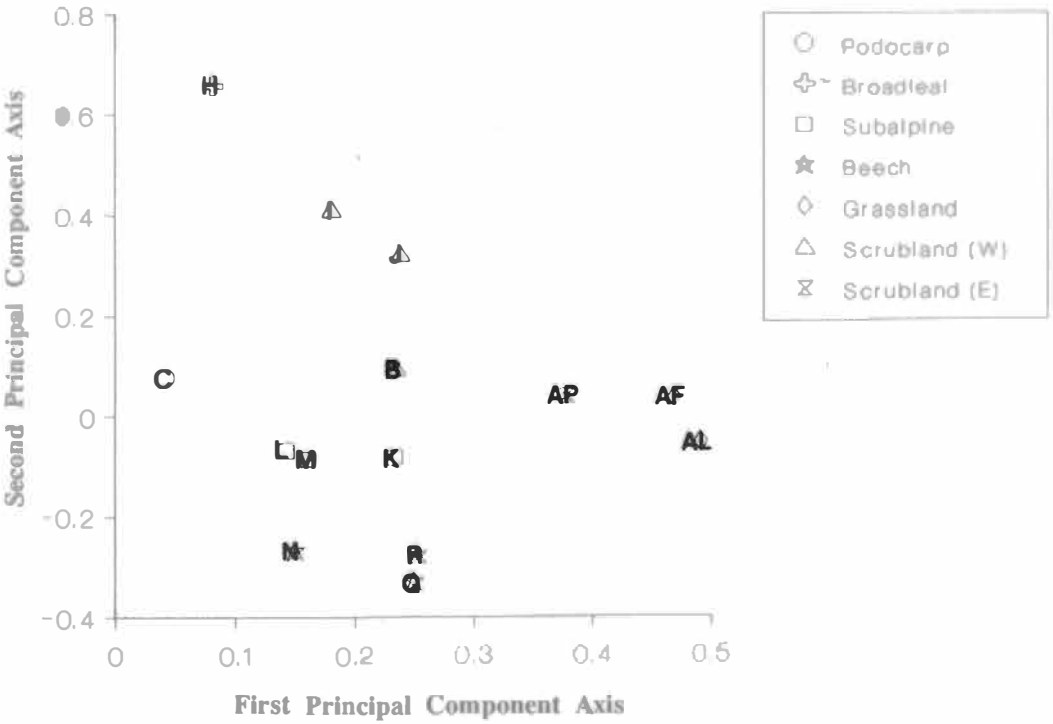


Figure 4.6b Plot of the 14 surface samples on the first and second principal components axes using unstandardised percentage data. The vegetation type from which the samples were collected are also shown.

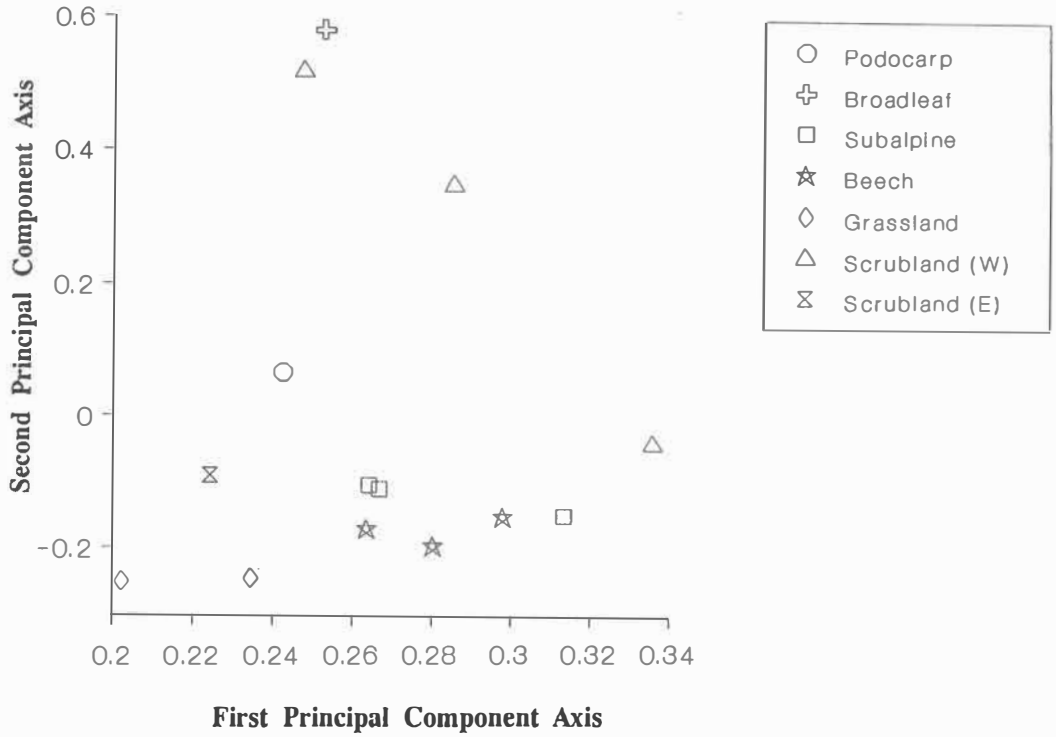


Figure 4.6a Plot of the 14 surface samples on the first and second principal components axes using log transformed 'absolute' values. The vegetation type from which the samples were collected are also shown.

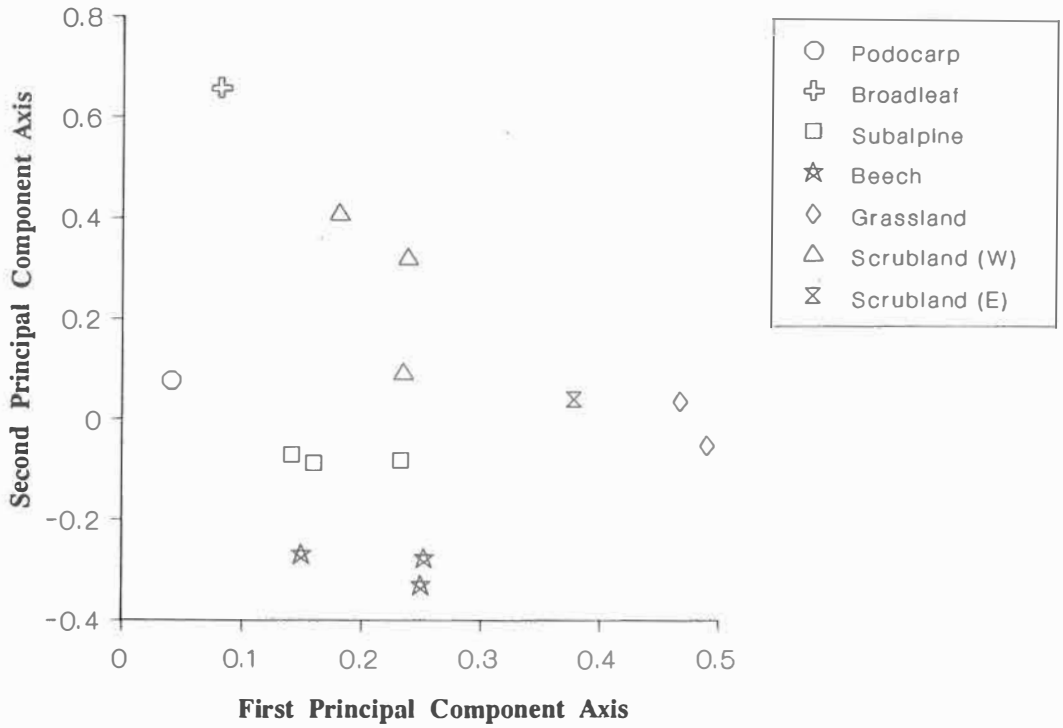


Figure 4.6b Plot of the 14 surface samples on the first and second principal components axes using unstandardised percentage data. The vegetation type from which the samples were collected are also shown.

3. Pollen dispersal depends on the position of the plants in relation to atmospheric turbulence, wind speed and direction, terminal velocity which depends on the size and other characteristics of the pollen grain and height of the pollen source.

4. Important features for pollen deposition (sedimentation) are the level of surface roughness (i.e. forest vs grassland) and the condition of the deposition surface. Roughness enables pollen to fall into air that is moving more slowly, allowing deposition (Benninghoff 1987).

5. Pollen preservation.

Pollen production in relation to the vegetation is complex and difficult to analyse (Birks and Birks 1980; Birks and Gordon 1985). This is due to special local factors such as vegetation, topography, weather patterns being different at each site such that generalisation from individual results are difficult.

In places of average wind flow (2-4 m/sec), pollen and spores have little tendency to settle under the influence of gravity; they normally move in a horizontal direction as a result of wind currents (Tauber 1965). Tauber proposed that pollen deposition in a temperate deciduous forested area consists of three components: pollen derived from (i) trunk space, (ii) above the canopy, and from (iii) washout by rain. The contribution of these three components to the total deposition will vary with the size of the basin, the denseness of the surrounding vegetation and with climatic conditions. This may not be applicable to New Zealand as the forests are evergreen and multi-storied with many entomophilous taxa.

Janssen (1966) suggested another theory, which describes the relationship between the amount of pollen deposited at a site and the area from which the pollen originated (Table 4.2, Figure 4.7).

Table 4.2 The area from which pollen originates and the expected values and variation with distance. (cf. Janssen 1966; Jacobson and Bradshaw 1981).

Pollen Deposition	Distance from source	Expected pollen values	Variation over distance
Local	within 20 m	high	variable
Extralocal	20 - 100s* m	medium	moderate
Regional	> 100s* m	low	small

* = several hundred metres.

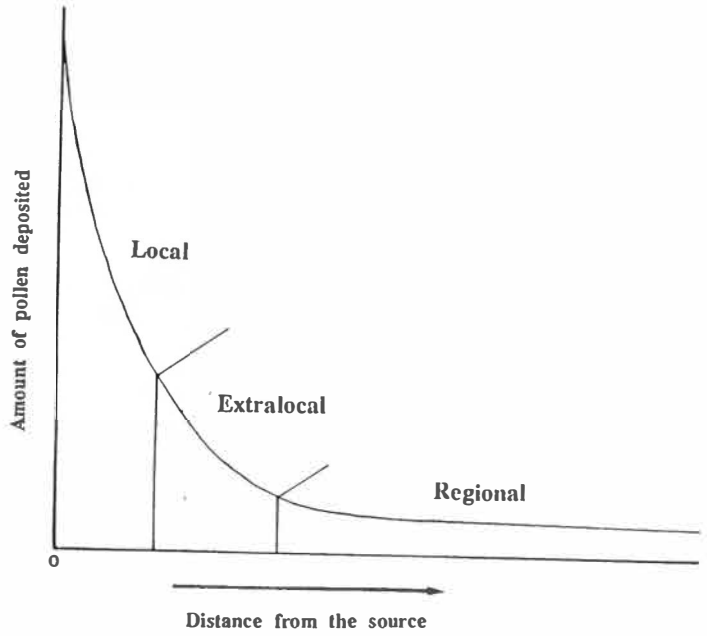


Figure 4.7 Graph showing the theoretical decrease in pollen deposition away from the source and the amount of pollen expected in local, extralocal and regional components. (after Janssen 1966).

Local is within 20 metres of the source. The pollen dispersal curve is high at the left and the amount of pollen deposited will be highly variable over a short distance. The distance of local deposition will be different for each taxon (i.e. local deposition for beech would be within 100 m, but for *Dracophyllum* local is within a metre).

Regional is at a great distance from the source, the pollen dispersal curve evens off, almost parallel to the X-axis. In this area the pollen values will not vary greatly with distance A feature of pollen composition is that pollen is independent of local situations.

Extralocal refers to an intermediate area in which the pollen deposition does not vary over a short distnce but has a higher value than in the regional part of the curve.

It is important to determine the source area of the various pollen types, as different pollen taxa will have different dimensions for the source area.

4.9.1 Percentage data

The samples collected from openings in the forest are dominated by the pollen from the trees that surround the site. Thus, *Dacrydium cupressinum* is the dominant pollen in the rimu/broadleaved forest, *Metrosideros*, *Quintinia* and *Weinmannia* in the broadleaved forest and *Nothofagus* in the beech forest. Poaceae dominates in the open grass/scrubland sites. The anemophilous taxa dominate the pollen spectra at most sites and are present in some quantity at a distance from their source. There are some exceptions to this, such as *Dacrycarpus dacrydioides*, *Lagarostrobos colensoi*.

Halocarpus type, *Podocarpus totara* type which often are present in only low amounts. Low percentages of these taxa do not necessarily imply absence or rarity in the vegetation.

Because many species are entomophilous and the plants relatively small the complexity of the forests is not well indicated by the pollen record. *Aristotelia, Fuchsia, Pseudopanax, Pittosporum, Myrsine, Pseudowintera*, for example are consistently and abundantly present in the understorey but are only represented by a few grains in the pollen spectra.

The hill slope forest in Westland is dominated by *Metrosideros umbellata, Quintinia acutifolia*, and *Weinmannia racemosa*; these are barely represented in the pollen deposition in most of the Westland grassland sites.

A feature of the pollen spectra from the subalpine sites on the Main Divide is the high percentage of pollen derived from anemophilous trees growing in the lowland forest and the upper slopes of the Otira valley to the west and the montane forest to the east. These mask the open treeless feature of the local vegetation in which, with the exception of grasses and sedges, most of the dominant plants are entomophilous. Therefore the results do not show that *Dracophyllum, Hebe, Celmisia* or *Olearia* are important components in the subalpine vegetation.

All of the samples from the beech forest are dominated by *Nothofagus fusca* type pollen. Other major pollen types include the shrubs *Phyllocladus, Halocarpus bidwillii* and Poaceae. *Phyllocladus* has low values except at site P (17%) in which there are several shrubs within 5 m of the sampling site. The values of *Halocarpus* are dependent upon the proximity to the sites. Its highest value at site R (26%) is due to the fact that *Halocarpus bidwillii* covers most of the surface of the bog and sampling was within 1 m of the shrub. Poaceae has values of 4-13%, most likely derived from grasses growing on or near the sampling sites.

The dominant feature of the scrub/grasslands from both the western and eastern sites is the high percentage of Poaceae pollen. The scrub/grasslands are very similar in their pollen spectra with some minor differences. These are: 1. A higher value of *Nothofagus fusca* type pollen and lower values for Poaceae in scrubland; and 2. Higher values from the shrub species (*Coprosma* and *Leptospermum*) in the scrubland.

Pinus is recorded in all samples, a reflection of the widespread occurrence of this introduced tree in parts of the study area, as well as the rest of the country.

Plantago lanceolata and *Rumex acetosella* are introduced species associated mainly with pastoral conditions or disturbed roadside verges.

These features of the moss polster results are similar to those observed by Moar (1970, 1971), Pocknall (1978, 1980), and McGlone (1982).

In studying modern pollen deposition it would be desirable to know the relationship between a taxon pollen percentage and the abundance of that taxon in the surrounding vegetation. Davis (1963) proposed a method which uses the abundance of taxa and the pollen frequency to calculate the R-value, the ratio between the percentage of a given taxon in the pollen deposition to its percentage in the vegetation. Janssen (1967) showed that the R-value can vary tremendously even in the same general area. The main problem is that the R-values tend to be too large when the taxon is really rare or absent in the surrounding vegetation and too small when the taxon is locally abundant. Birks and Birks (1980) discuss the difficulty in using R-values and their limitations. In New Zealand, the R-value was found to be of limited application (Pocknall 1978).

For these reasons and also because of the lack of abundance data for plants in the vegetation no attempt was made in this study to apply R-values. Using the pollen spectra from the surface samples, an attempt was made to compile the expected percentages of the major taxa found in the study area and whether the taxon value indicated a local, extralocal or regional value (Table 4.3). This was done by assigning the percentage values to either local, extralocal and regional, based solely on whether the taxon occur on or near the site or at some distance using the criteria in Table 4.2 and Figure 4.7. With this information it should be possible to determine if the taxon is present or at some distance from the source, based on its pollen percentage. The problem of a few trees close to the site and many at some distance will still apply (Oldfield 1970).

Unstandardised percentage data were prefered to standardised values because four pollen types, *Dacrydium cupressinum*, *Metrosideros umbellata*, *Nothofagus fusca* type and Poaceae account for 64% (75% 'nwf') of the total pollen sum. The other 36% (25%) is divided between a further forty eight (37) taxa. The inflation of these minor variables by standardisation to equal variances would be without analytical justification (O'Sullivan and Riley 1970; Prentice 1980, 1983).

The Principal Components Analysis of the surface transect of the 'all' data depicts the separation of the vegetation types into six groups, beech forest, subalpine, podocarp/broadleaved, western scrubland, eastern scrubland and the grasslands.

Table 4.3 Expected percentage values for pollen types in the local/extralocal and regional components.

Taxon	Local/extra local	Regional
Dacrycarpus dacrydioides	-?-	Trace to 2%
Dacrydium cupressinum	29-46%	Trace to 12%
Halocarpus type	1-26%	Rare
Lagarostrobos colensoi	-?-	Trace
Lepidothamnus	3-12%	---
Podocarpus totara type	1-6%	Trace to 1%
Prumnopitys	2-6%	Trace to 19%[1]
Pinus	-?-	Trace to 23%
Phyllocladus	4-17%	Trace to 8%
Cupressaceae	-?-	Trace to 1%
Aristotelia	Trace to 2%	---
Ascarina	Trace to 2%	Trace to 2%
Hoheria	Trace to 3%	---
Metrosideros	6-59%	Trace to 4%
Muehlenbeckia	Trace to 3%	-?-
Nothofagus fusca type	43-84% (20-46%)[2]	Trace to 16%
N. menziesii	-?-	Trace to 1%
Quintinia	3-10%	Trace to 2%
Schefflera	Trace to 1%	---
Weinmannia	1-5%	Trace
Coprosma	4-9%	Trace to 3%
Discaria	Trace to 2%	---
Epacridaceae (cf *Dracophyllum*)	Trace to 1%	Trace
Leptospermum	Trace to 6%	Trace
Myrsine	3-10%	Trace to 2%
Apiaceae	Trace to 14%	Rare
Asteraceae	Trace to 10%	Trace
Bulbinella	Trace to 2%	---
Coriaria	1-20%	Trace?
Papilionaceae	Trace to 3%	---
Phormium	Trace to 1%	---
Plantago (indigenous)	Trace to 1%	-?-
Plantago lanceolata	Trace to 17%	-?-
Poaceae	4-88%	-?-
Ranunculus	Trace to 6%	---
Rumex	Trace to 7%	-?-
Taraxacum type	Trace to 15%	-?-

Key

-?- Not possible to determine as these taxa occurred throughout the study area.
--- Not expected to occur.
1 Main deposition for *Prumnopitys* was on the Main Divide where this taxon is absent.
2 Extralocal value.
NOTE: Only those taxa used in the pollen sum (Figure 4.1) are presented.

The 'nwf' depicts a similar pattern, with more distance between the groups and a clearer separation of the eastern scrubland from the grassland sites and the Westland from the Canterbury grasslands. In both the 'all' and 'nwf', two of the scrubland sites (AO and AP) group with the grassland. This is expected, as both sites are in the *Dracophyllum*/tussock grassland, in which the pollen from the tussocks is dominant. In the Principal Components Analysis of the 'four taxa' the same pattern is observed with more compact groups for the beech forest and the grassland sites. The subalpine sites are more separated, as are the western scrubland sites, due to the different values for the four taxa. The subalpine and the Westland sand dune sites group in an intermediate position, as these sites are dominated by the regional rather than local vegetation.

The cluster analysis displays some finer grouping than does the PCA. Group average linkage of the 'all' data depicts similar groups as for PCA, except that: 1. Group average suggests a closer similarity of the subalpine (site K, L and M) and the Westland coastal site (A) to that of the podocarp/broadleaved site (C); 2. Site H is depicted as an outlier, as are sites B and W. This is because each of these sites is dominated by a single pollen type *Metrosideros*, *Dacrydium cupressinum*, and *Haloragis* respectively. Single linkage depicts much the same as group average linkage. Site H is still an outlier.

The cluster of 'nwf' depicts a similar but more compact pattern than the 'all' data set. The main differences are: 1. The subalpine and the Westland coastal site form a cluster; 2. Sites B and C are closer than suggested by PCA; and 3. Site H is an outlier which is not suggested by the PCA. Single linkage suggests that there are two major groups, beech forest and grass/scrubland.

The two numerical methods display much the same pattern. PCA depicts the major groups and cluster analysis does the 'fine tuning' of the data sets. The slight differences between the various data sets and methods may be a result of the imposition of arbitrary divisions by the numerical analyses upon a continous gradient of varying pollen composition. The groupings of sites by both PCA and CA are similar to those observed by Norton *et al.* (1986).

The PCA suggests that four pollen types (*Dacrydium cupressinum*, *Metrosideros*, *Nothofagus fusca* type and Poaceae) are the main factors in determining the separation of the major vegetation types. The minor variation seen within each group is due to the presence of the other taxa.

4.9.2 'Absolute' data

Pollen concentrations (grains gm^{-1}) and accumulation rates (grains cm^{-2}) are attractive ways of analysing data, because the changes of a single pollen taxon through time is independent of other taxa in the pollen spectra (Maher 1981, Birks and Gordon 1985). For example the number of beech pollen grains gm^{-1} will increase if there are more trees in the area or if they are closer to the site of deposition. Beech concentration will increase if the sedimentation rate has slowed so that more years of pollen production are included in the sample. Pollen concentration and accumulation rates can help view the problem from perspectives not possible with percentages.

Pollen accumulation rates for a particular taxon are considered to be independent of other pollen types (Walker and Pitelkow 1981; Birks and Gordon 1985) though some suggest that this is not strictly true and that PAR are subject to greater variability between samples than are percentage data (Davis *et al.* 1973).

When the results of the pollen concentration study were examined without the aid of the 95% confidence intervals, the initial conclusion was that a taxon was very variable in its' pollen concentration at the different sites. This seems likely to arise from differences in the effectiveness of various species of moss as pollen traps (Boyd 1986). What would account for the differences and how could this be detected? At the 14 sites, various species of moss were collected (Table 4.1). The different length of time represented by each moss polster (Carroll 1943) and the difference in the ratio of surface area to the weight or volume of the moss (Boyd 1986) may be responsible for the variation shown in pollen concentrations (Appendix D). The use of 95% confidence intervals should give an estimate of the amount of variation that may exist within a sample (Figure 4.5 and Appendix E). One would expect the local species to have highly variable input, but the regional taxa should be very similar, due to mixing of the pollen, producing an even deposition (Tauber 1965; Janssen 1966).

Useful 95% confidence intervals (limits) can be applied when the number of markers counted are equal to, or greater than 100 and when the number of pollen grains of the taxon of interest is equal to, or greater than four (Maher 1981). Four of the sites (B, H, I, and AF) had less than 100 markers counted, even after an increased pollen count. The percentage remained the same with the increased count and the mean value remained similar, but with reduced upper and lower limits.

Table 4.4 Pollen count, concentration and percentage values for two samples (from the same location) using different numbers of marker *Lycopodium*.

TAXON	2 raw count	10 raw count		2 per gm	10 per gm	2 %	10 %
Dacrydium cupressinum	2	2	u	6163	8168		
			x	1497	2067	0	0
			l	363	523		
Podocarpus totara type	6	1	u	10831	6902		
			x	4490	1033	0	0
			l	1861	155		
Prumnopitys	7	3	u	11986	9642		
			x	5238	3100	1	0
			l	2289	997		
Phyllocladus	1	3	u	5168	9642		
			x	748	3100	0	0
			l	108	997		
Hoheria	12	6	u	17670	14064		
			x	8979	6200	1	1
			l	4563	2733		
Metrosideros	688	431	u	750701	552258		
			x	514814	445367	53	62
			l	353047	359164		
Nothofagus fusca type	7	4	u	11986	11131		
			x	5238	4133	1	1
			l	2289	1535		
Quintinia	63	37	u	73582	55676		
			x	47141	38233	5	5
			l	30202	26255		
Weinmannia	88	48	u	100737	69878		
			x	65848	49600	7	7
			l	43043	35206		
Coprosma	11	9	u	16543	18347		
			x	8231	9300	1	1
			l	4095	4714		
Asteraceae	12	7	u	17670	15506		
			x	8979	7233	1	1
			l	4563	3374		
Coriaria	98	17	u	111588	29335		
			x	73331	17567	8	2
			l	48109	10520		
Papilionaceae	8	4	u	13134	11131		
			x	5986	4133	1	1
			l	2728	1535		
Phormium	12	5	u	17670	12606		
			x	8979	5167	1	1
			l	4563	2118		
Poaceae	91	33	u	103993	50476		
			x	68093	34100	7	5
			l	44586	23037		
Taraxacum type	30	8	u	37592	16933		
			x	22448	8267	2	1
			l	13405	4036		
Total Pollen	1288	700	u	1400467	889668		
			x	963779	723333		
			l	663257	588096		
Total Markers	29	105					

Key

2 = one gram sample with two *Lycopodium* tablets added.

10 = one gram sample with ten *Lycopodium* tablets added.

95% confidence limits for concentration values were calculated. (u = upper, x = mean, l = lower limit).

Note: Each tablet contains 10850 ± 200 *Lycopodium* spores (Stockmarr 1971).

To determine if the high concentration values for the pollen types at these four sites are correct, or due to the low recovery of exotic markers at one of the sites (Barrack Creek), a new sample was collected in September 1989. The sample was dried and two, one gram samples were removed. One of the samples had two *Lycopodium* tablets added and the second sample, 10 tablets. These were processed as before. The results of the raw counts, the pollen concentrations with 95% confidence limits and the percentage for the major taxa are displayed in Table 4.4. Generally, those taxa in which the pollen originates some distance from the site have very similar concentration values. Those taxa which are on the site (e.g. *Coriaria*, Poaceace and *Taraxacum* type) have different values between the samples as the local pollen producers will be highly variable (Ritchie 1974; Solomon and Silkworth 1986). The main feature to note is the high value for *Metrosideros* which is 7 to 8 times greater than either *Coriaria* or Poaceae, the taxa with the next highest concentrations. Though the concentration values between the 1989 sample and that collected two years previously were not the same, the trend regarding the pollen concentrations were similar (N.B. The percentage values of those three samples were similar). The mean values of some taxa are very similar between the samples, with the main difference being that the confidence interval is larger in the samples with only two markers added. Though the 95% confidence intervals for the four sites (B, H, I, and AF), may be greater than the true value, the mean concentration should be reasonably accurate.

The Principal Components Analysis of the concentration and percentage values suggest similar conclusions. Both axes account for the same amount of variance in the data set. The percentage values produce more distinct groupings than do the concentration values.

4.9.3 Comparison of the pollen trap and the moss polster results

The results from the pollen traps and moss polsters are not directly comparable, as different measurement units were used (cm^{-2} vs gm^{-1}) (Boyd 1986). The pollen traps represent one year of deposition and the moss polsters several years, however the patterns should be indirectly comparable.

The pollen traps show a high value for *Metrosideros* at Barrack Creek reducing to half as much at Otira Gorge and then declines rapidly eastwards. *Quintinia* and *Weinmannia* show a similar trend. This also occurs in the moss polsters from those sites.

The pollen traps have higher values of beech pollen in the open than in the forested sites. The polsters show that the forest and grassland have similar values.

The trap results show that Poaceae has its highest value at Otira Gorge (5874 cm^{-2}) which is twice as much as at Lake Hawdon (3447) and Cave Stream (3762). Lake Hawdon and Cave Stream have similar values. The moss polster has the highest concentration at Otira Gorge, about twice as much as for Lake Hawdon and Cave Stream. Lake Hawdon and Cave Stream have similar concentrations. At Otira Gorge, the site consists of a small opening (4 m X 2 m) with adventive grasses and *Coriaria* the dominant taxa surrounded by various shrubs. The high deposition for Poaceae results from these taxa's pollen being directly deposited into the traps and moss polster.

The pollen traps collected high amounts of Cyperaceae pollen at Lake Hawdon and less but high amounts at the Main Divide and Cave Stream sites. The moss polster confirms this pattern.

In traps, *Taraxacum* has its highest accumulation rates at Lake Hawdon and Cave Stream. Barrack Creek, Otira Gorge, Rolleston River have low but similar values. The polsters show that Barrack Creek (47345 gm^{-1}), Otira Gorge (35054) and Rolleston River (47306) have similar concentration values, but these are much higher than for Lake Hawdon (11543) and Cave Stream (1085) and that Cave Stream has a low concentration of *Taraxacum* type pollen.

From traps, the *Coriaria* accumulation rate is highest at Barrack Creek and Otira Gorge with reduced values eastwards. The same trend is evident in the moss polsters.

Pinus shows much the same pattern from the pollen traps and the moss polster, with similar values for most of the sites.

Total pollen accumulation rate in the pollen traps is highest at Barrack Creek and Bealey River has the lowest rate. Lake Hawdon and Cave Stream have similar accumulation rate, and Rolleston River and Main Divide have approximately half as much. The moss polsters show that Barrack Creek has the highest, but Main Divide the lowest concentration values. Like the traps, polsters from Otira Gorge have the second highest values. Rolleston River, Lake Hawdon and Cave Stream have similar values in the polster.

Percentage results from the pollen traps (Table 3.7) were compared with the percentage calculated from the concentration results (Appendix F). The podocarps have low percentage in the traps and moderate values in the moss polster. *Pinus* has similar values in both traps and polsters. Barrack Creek traps have a higher percentage of *Metrosideros* than the moss polster, but similar percentages were at the sites further to the east. *Quintinia* and *Weinmannia* have higher percentages in the moss polster than in the traps. *Nothofagus* has similar values from both the traps and polsters.

Coprosma has higher percentage in the traps. Cyperaceae has a higher value in the moss polster from site K, then in the trap, but similar values were obtained from the traps and polsters at Lake Hawdon and Cave Stream. At Barrack Creek, Otira Gorge and Rolleston River, Poaceae has similar values in both the traps and moss polster. However, Poaceae has a higher percentage from the polsters from Lake Hawdon and Cave Stream than from the traps.

The results from the pollen traps, though not directly comparable with the moss polsters, thus, show similar patterns. Some of the differences observed could arise because the traps record palynomorphs from one flowering year and the moss polsters those from several flowering seasons. There are no published studies in New Zealand which describe results from pollen trapping or concentration values. Pollen concentration studies have been conducted overseas (e.g. Davis *et al.* 1973; Pennington 1973; Peck 1973; Mathewes 1988). These and other studies (Davis *et al.* 1973, Table 4) present their results from lake sediments as grains cm^{-2} $year^{-1}$ and thus they are not comparable to the present study.

4.9.4 *Metrosideros*, *Dacrydium cupressinum* and *Nothofagus* Pollen Concentration

Both traps and polster results confirm the very high values of *Metrosideros* pollen are deposited at Barrack Creek and Otira Gorge, even though the sites are 500 m from the forest. What could be the reason for this high concentration in both the pollen traps and the moss polsters? *Metrosideros* is bird-pollinated but bees also collect the nectar.

A dozen beehives were located within 250 m of the sampling sites while the rata was in flower. Could the high pollen counts of *Metrosideros* be due to bee activity in the area? *Metrosideros umbellata* is a predominant source of nectar for bees in the Otira Gorge (Seal 1957) and *Weinmannia* is also important. When the rata is in flower, bees abandon all other sources of nectar (Myers 1945). Honey bees usually defaecate in flight and not in their hive (Ashton *et al.* 1983; Dr. N.T. Moar pers comm). The traps were not examined for yellow rain, but with the high rainfall in the area, the pollen would have been dispersed in the trapping medium. A 3 mm spot of yellow rain from southeast Asia yielded 1.1×10^5 pollen grains (Nowicke and Meselson 1984). The apparently anomalous high *Metrosideros* value might otherwise have arisen not from bee faeces, but possibly through the dropping of pollen balls from the bees' legs as they return from the pollen source to the hive (Peter Johns pers comm). Another possibility could be that the bees voluntarily discard the *Metrosideros*

pollen while collecting the nectar (Butler 1949). This pollen would then fall onto the sampling site. The most probable source is thought to be the bee faeces.

The high *Dacrydium cupressinum* at site B may be due to local site conditions. The area where the sample was collected is subject to flooding due to the high rainfall in the area. There are numerous small 'streams' which could pool the pollen and concentrate it in the moss polster. Therefore the high rimu concentration may be predominantly the result of inwashing and not from aerial deposition.

Similar deposition of *Nothofagus fusca* type pollen in both forest and grassland sites were observed from the pollen traps and polsters. Similar results have been observed in North American studies (e.g. Davis *et al.* 1973). This results from a greater number of trees represented in the pollen deposited in the grasslands than in the forest sites.

4.9.5 Upslope Transport of Pollen

The upslope transport of pollen has been reported by numerous workers both in New Zealand (Moar 1970; Pocknall 1982) and overseas (Maher 1972b; Hope 1976; Markgraf 1980; Kearney 1983). Is the apparent increase of pollen upslope caused by an increase in the amount of pollen on those high elevated sites in real terms or is it an artefact due to low pollen production of the subalpine/alpine species? The facts from this study seem to suggest that the latter is the case. The 'absolute' data do not indicate a significantly greater amount of pollen uplifted and deposited on those sites, but that these are the same amounts that would be deposited at that distance from the source whatever the terrain might be (cf Janssen 1966 regional deposition; Tauber 1965 rain-out component). The impression from the percentage data that upslope transport increases the amount of pollen deposited on these sites, is in reality, the result of both the low local pollen production and that many of the plants in the subalpine/alpine are entomophilous. This is compounded by the fact that some high pollen producers at the subalpine sites (Cyperaceae, Centrolepidaceae) are not used for the pollen sum calculations. Upslope transport of pollen occurs, but it does not totally mask the subalpine/alpine pollen spectra. Their pollen spectra were able to be distinguished by use of numerical methods. Similar results were observed by Markgraf (1980), Solomon and Silkworth (1986) and Mathewes (1988).

4.10 CONCLUSION

Many of the sites in the study area are not pristine, but were modified originally by the Polynesians and then more recently by the European settlers. Notwithstanding this, the results show that modern pollen deposition in moss polsters is representative of the major vegetation types in the region, despite the widespread dispersal of some pollen types (*Dacrydium cupressinum* and *Nothofagus fusca* type) and the under-representation of others (*Metrosideros*, *Quintinia*, *Weinmannia* and most herbaceous taxa).

Many of the understorey species which are mostly entomophilous, are represented either by a few grains, or none at all, even if they form a major component of the understorey. Only the major canopy taxa (which are mostly anemophilous) are present in the pollen spectra.

The anemophilous species are important in modern pollen deposition and this study confirms previous studies done in New Zealand (Moar 1970; McGlone 1980; Pocknall 1978, 1980, 1982).

The percentage data predominantly reflect the composition of the local vegetation (Figure 4.8). Only the moss polsters from sites on the Main Divide and the Westland coastal sand dunes indicate more of the regional vegetation.

Since the 'absolute' values were derived from a preliminary study, only broad generalisations can be made. More sampling would be needed before discussion of the fine details could be considered, due to the numerous variables in determining the true values. The 95% confidence intervals assist in determining the amount of variation that may exist in the samples. The values from each site may reflect the different number of years represented by the individual moss polsters, and the number of grains found, input by local species, number of markers counted etc. The use of 'absolute' values has given some insight into the relative values of the 'absolute' numbers and assisted in determining what is happening to the pollen from the release point to deposition. The local herbaceous taxa (e.g. Asteraceae, Cyperaceae, Poaceae and *Taraxacum* type) have highly variable concentrations between the different sites, while the tree and shrub taxa (both anemophilous and entomophilous) have high, variable values near their source and low even values in the regional deposition. Open sites receive greater amounts of pollen then do forest and subalpine sites.

The 'absolute' values suggest that the regional deposition along the length of the transect is in similar amounts, with increased local input by certain particular taxa wherever they occur along its length (Janssen 1970). The values also suggest that the input of the regional pollen is often masked

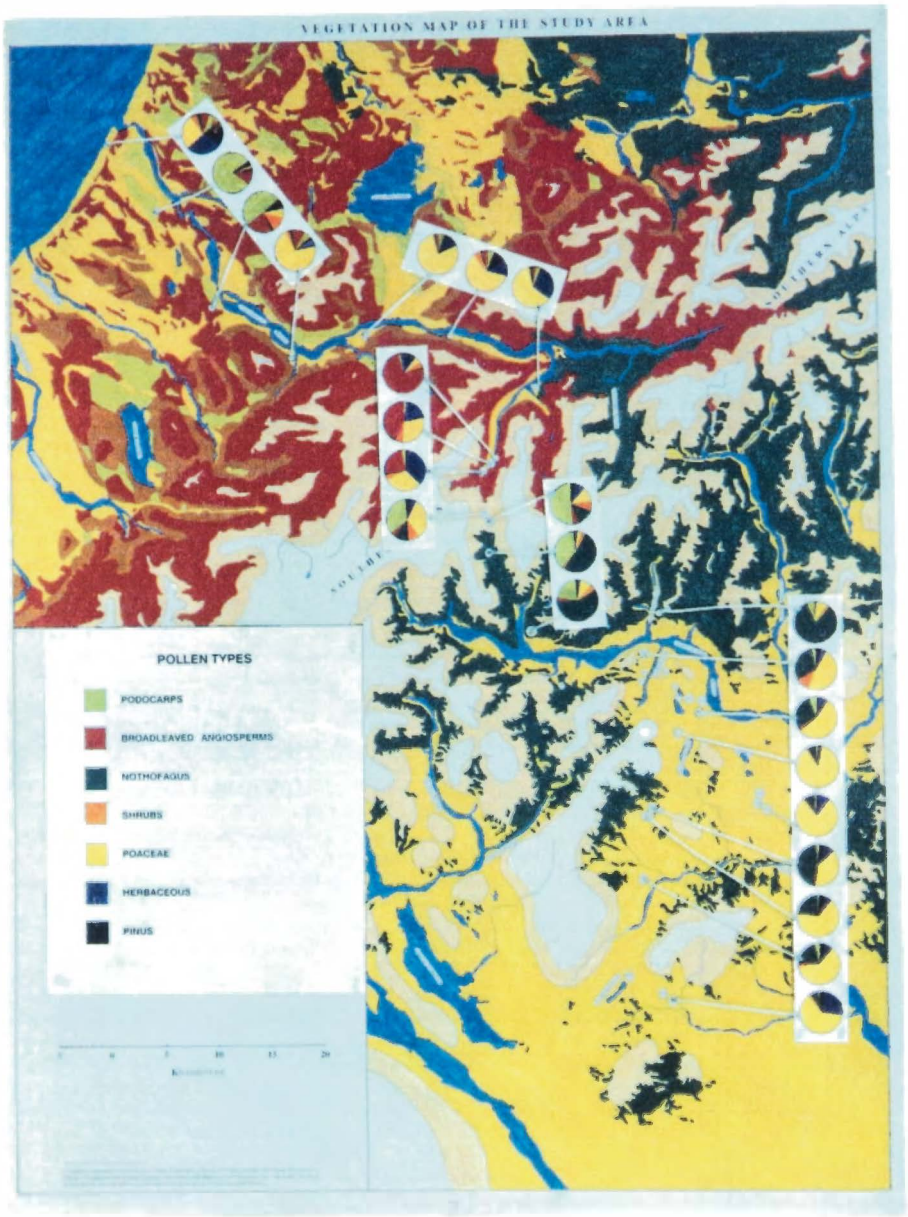


Figure 4.8 A general presentation of the pollen percentages along the transect. Only selected sites are displayed. The pies represent 7 general pollen types:
Podocarps, Broadleaved angiosperm trees, *Nothofagus*, Shrubs, Poaceae, Herbaceous taxa and *Pinus*. Note that local vegetation types dominate at all the sites, except at site A and the sites on the Main Divide. For vegetation types refer to Figure 2.8.

by the local pollen producers. Ritchie (1974) observed similar results in the Canadian Arctic. Upslope transport of pollen from the lowlands and montane slopes to Main Divide sites does not mean an increase in the amount of those pollens deposited, nor does it mask local pollen spectra.

In this study, the total pollen concentration at some sites is high compared to other sites. This may be a reflection of a greater input of pollen to those sites. It does not appear to be due to the different moss species' ability to trap pollen.

The consistency of the results of the numerical methods (PCA and cluster analysis) indicates that the proposed groupings of the data are not artifacts of any one numerical procedure. These methods have aided in identifying more clearly which taxa are to be considered in the definition of different vegetation types.

CHAPTER 5
PEAT MONOLITHS

5.1 INTRODUCTION

Fine resolution palynological techniques were applied to three short peat monoliths to establish the immediate past history of pollen deposition and vegetation in the study area. The resulting pollen diagrams were used to interpret environmental history of the sites and the region. A peat monolith was collected to ensure an adequate sample for radiocarbon dating.

5.2 LOCATION OF PEAT MONOLITHS

Peat monoliths (380 to 420 mm long and 200 mm in diameter) were collected from the following sites:

1. Lower Bog, Main Divide (site K)
2. Bealey River (site N)
3. Cave Stream (site AL)

The length of the monoliths were considered sufficient to probably pre-date human impact in the area. The monoliths from the Main Divide and Bealey River sites were taken from the centre of the bog. The Cave Stream site was not a large bog and appeared to be of recent age, so it was probed to find the deepest part and the monolith was taken at that point.

5.3 COLLECTION OF PEAT MONOLITHS

Monoliths were collected using 500 mm lengths of PVC tube of 200 mm diameter (Figure 5.1). These tubes were pushed into the bog, a hole was dug alongside, the bottom of the monolith was cut and then the tube with the monolith was removed from the bog. The tubes were sealed and then taken to the laboratory. The lowermost 80-100 mm of the monolith was discarded to prevent possible contamination caused while retrieving the monolith.

The remainder of the monolith was sectioned at 20 mm intervals and the 'slices' placed into separate plastic bags and stored under refrigeration until they could be processed further.

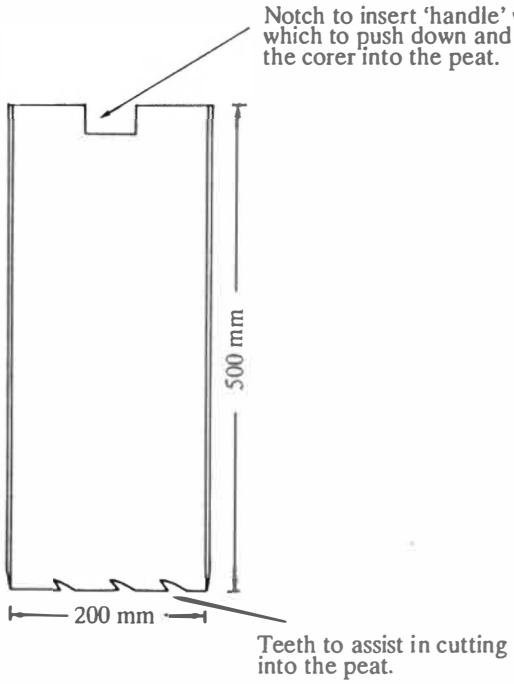


Figure 5.1 Schematic diagram of the peat corer used to obtain the monoliths.

A subsample from the center of each slice was taken and placed directly into a 50 ml boiling tube. These were treated with 5% sodium hydroxide and placed into a boiling water bath for 10 minutes during which time the samples were stirred to release trapped pollen grains and spores. The samples were then sieved and rinsed with distilled water. The residue was then treated with 40% hydrofluoric acid for 10 minutes in a boiling water bath to remove silicates. The procedure used to acetolyse the pollen was based on the standard acetolysis method (Faegri & Iversen 1964). The final residue was stained with 1% aqueous safranin. One drop of residue was added to four drops of melted glycerine jelly and thoroughly mixed on the slide, prior to the addition of a cover slip. Pollen counting and identification were as per Chapter 3 section 3.4.

The pollen sum used to derive the percentage values consists of all taxa which obtained a value of 1% or more in any one level, but excludes all wet site taxa and fern ('nwf') (for raw pollen counts see Appendices H, I and J).

5.4 RADIOCARBON SAMPLES

Samples were taken at the middle and bottom of each monolith for radiocarbon analysis. Roots which had grown down into the peat from living plants at the surface were removed. The samples were then air-dried and forwarded to New Zealand Radiocarbon Dating Laboratory, Institute of Nuclear Sciences, DSIR, Lower Hutt for age determination.

5.5 ANALYSIS OF THE SAMPLE DATA

The pollen percentage data had 95% confidence intervals calculated to determine whether the variation between levels were significant or random variations inherent in percentage data (Mosimann 1965; Maher 1972a; Maher 1981).

Principal Components Analysis and Cluster Analysis were performed on a combined data set using unstandardised, untransformed percentage data from the three monoliths. This data set was then combined with the surface transect data for a comparison between the 'fossil' and the 'modern' pollen data.

5.6 RESULTS

5.6.1 Main Divide Site

The peat monolith from the Lower Bog, Main Divide, taken from a bog dominated by *Donatia novae-zelandiae* and *Oreobolus pectinatus*, consisted of dark brown humified peat to 500 mm. The radiocarbon analysis determined that the 400-420 mm level was modern (less than 200 yrs B.P.) and the middle section (220-240 mm level) was post bomb (i.e. post 1950 A.D., but possibly contaminated through percolation of water from above). The full depth of the bog was not determined. Pollen data from the monolith (Fig. 5.2) show that there has been a steady deposition of pollen from the various Westland tree species (*Dacrydium cupressinum*, *Dacrycarpus dacrydioides*, *Prumnopitys*, *Metrosideros umbellata*, *Quintinia acutifolia* and *Prumnopitys*, *Metrosider* period of accumulation of the peat. Pollens which are probably almost entirely locally derived include *Lepidothamnus*, *Podocarpus totara* type, *Phyllocladus*, *Coprosma*, *Dracophyllum*, Asteraceae type, Apiaceae, Poaceae and *Rumex*.

A major area of beech forest is 500 m to the east of the site today and contributes consistently about 20% of the pollen. Grass pollen increases up the profile from 12% to 30% with the main increase occurring at 180-200 mm level and remaining constant to the present. A fire in 1890, which burnt over most of the area (Cockayne 1898; Calder & Wardle 1969), is indicated by microscopic charcoal present at 260-280 mm.

5.6.2 Bealey River Site

The Bealey River bog is situated within the *Nothofagus solandri* var. *cliffortioides* forest. The monolith from this site consists of uniform, dark-brown, well-humified *Donatia novae-zelandiae* and *Oreobolus pectinatus* peat. The depth of the bog is 5 metres. The 400-420 mm level (Fig. 5.3) was

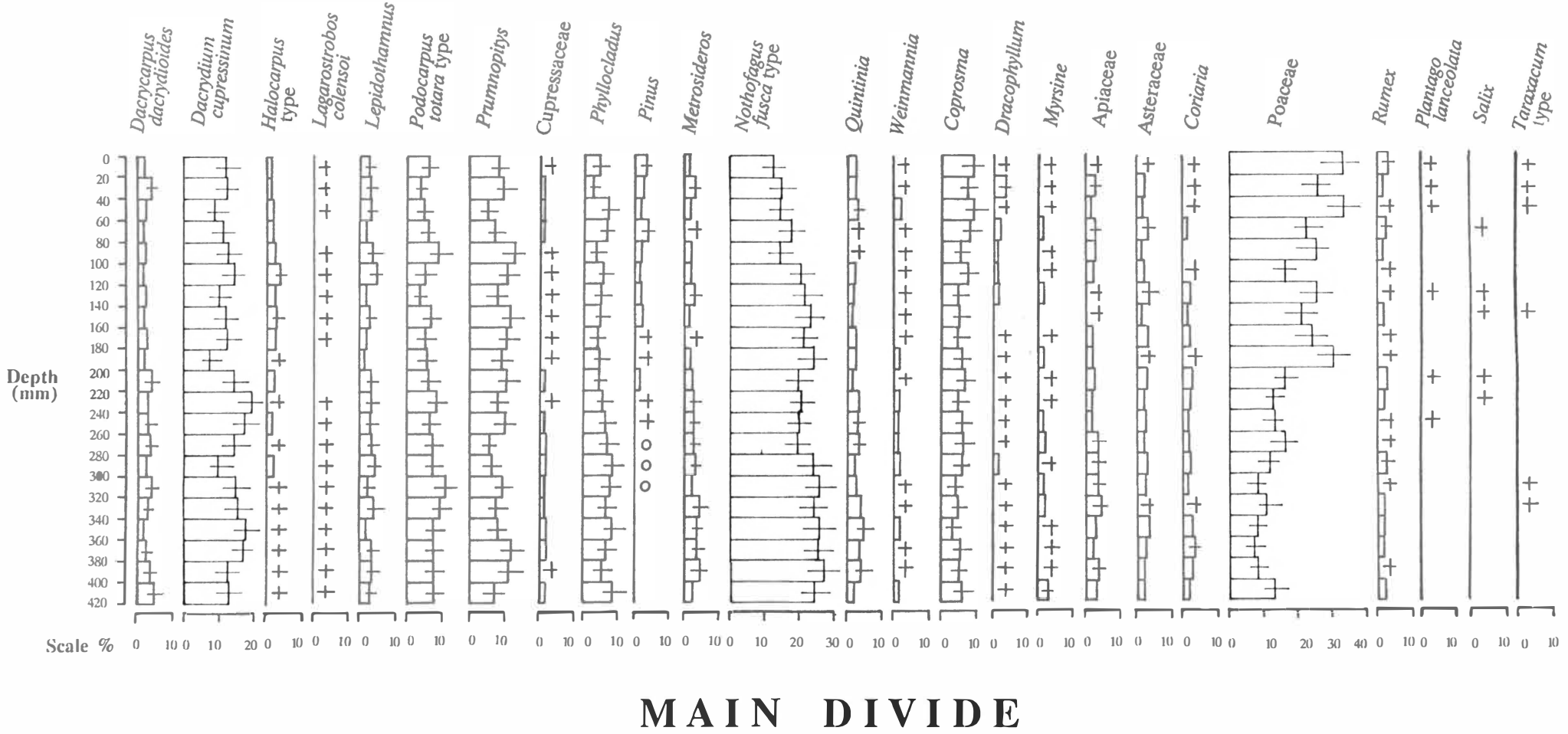


Figure 5.2 Pollen diagram from the Lower Bog (site K), at Arthur's Pass, on the Main Divide of the Southern Alps. The pollen sum is based on all terrestrial taxa which reached a value of at least 1% in any one level. (+ = trace, less than 1%; 0 = observed after the count).

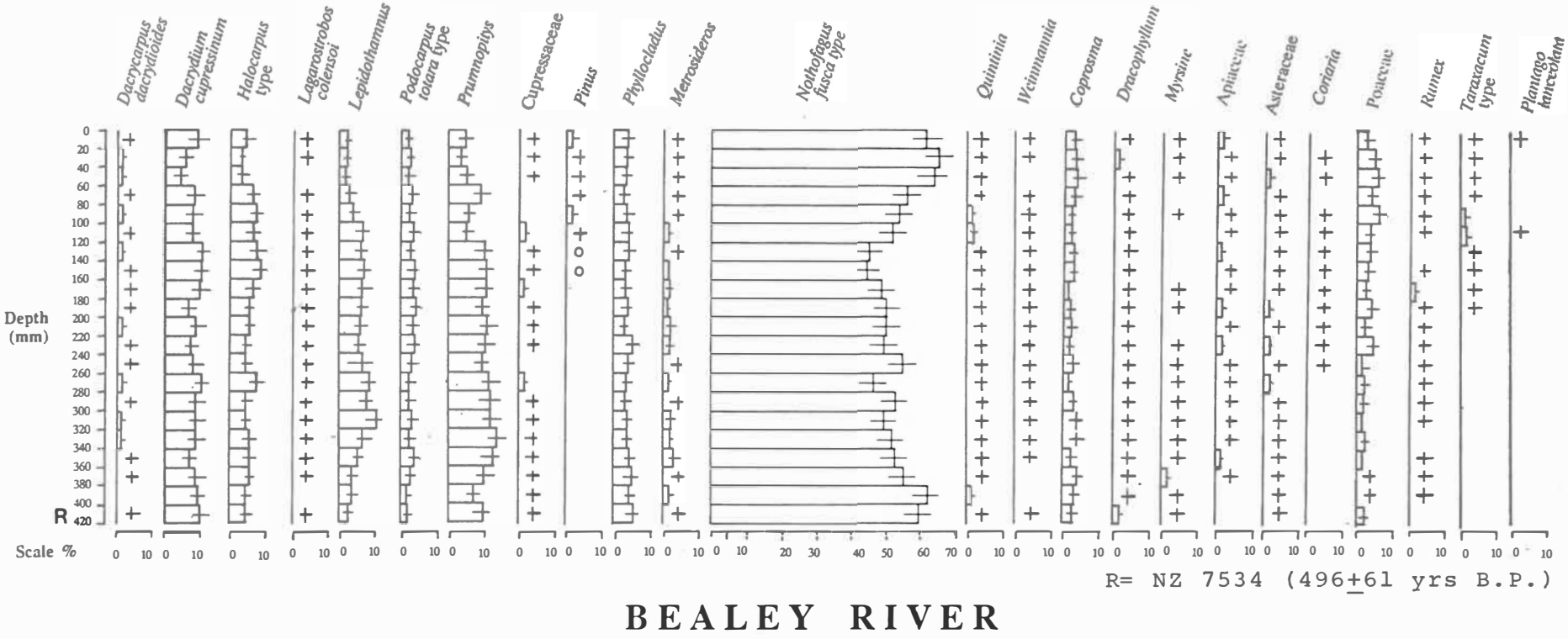


Figure 5.3 Pollen diagram from Bealey River (site N), Canterbury. The monolith was taken from within the *Nothofagus solandri* var. *cliffortioides* forest. The pollen sum is based on all terrestrial taxa which reached a value of at least 1% in any one level. (+ = trace, less than 1%; 0 = observed after the count).

dated at 482 ± 60 yrs B.P. (Libby $T_{1/2}$ 5568 yr) 496 ± 61 yr B.P. (New $T_{1/2}$ 5730 yr) (NZ No. 7534) but the middle section (200-220 mm) was post bomb as for the Main Divide samples.

The main features of the pollen profile are:

1. *Nothofagus fusca* type pollen has dominated for the last 500 years with some small changes;

2. There has been steady deposition of *Dacrydium cupressinum*, *Prumnopitys* (both about 10%), *Metrosideros umbellata* and *Quintinia acutifolia* and *Weinmannia racemosa* (in trace to low amounts) pollens dispersed to the Main Divide from the lowlands and mountain slopes in Westland;

3. The pollen percentages of shrub taxa *Phyllocladus*, *Halocarpus* and *Coprosma* have remained constant, as has the *Podocarpus totara* type;

4. *Lepidothamnus* increases slightly at 300-320 mm level and then declines at 80-100 mm level;

5. The occurrence of *Pinus* in the top third of the monolith (0-120 mm);

6. *Rumex*, native and adventive, *Taraxacum* and *Plantago lanceolata* are adventive roadside and pasture weed; and

7. Poaceae has shown a minor increase to the present.

5.6.3 Cave Stream Site

From Cave Stream, a 380 mm monolith through *Sphagnum* peat was taken. The monolith is composed of a light brown, humified, unconsolidated peat with some sedge remains. The 1020 mm of peat lies on alluvial gravel. Samples were submitted for radiocarbon dating but were withdrawn after the monolith was analysed. The pollen profile (Fig 5.4.) shows:

1. A decrease of *Nothofagus* type pollen from 50% (220-380 mm level) to 25% (0-220 mm level);

2. A decrease in the pollen of all shrub species (*Halocarpus*, *Phyllocladus* and *Coprosma*);

3. A constant increase in the grass pollen to the present;

4. The presence of microscopic charcoal from 220 to 380 mm level;

5. An immediate increase at 200-220 mm then decline in the amount of Apiaceae pollen following the fire;

6. The presence of *Pinus* pollen and its increase to the present; and

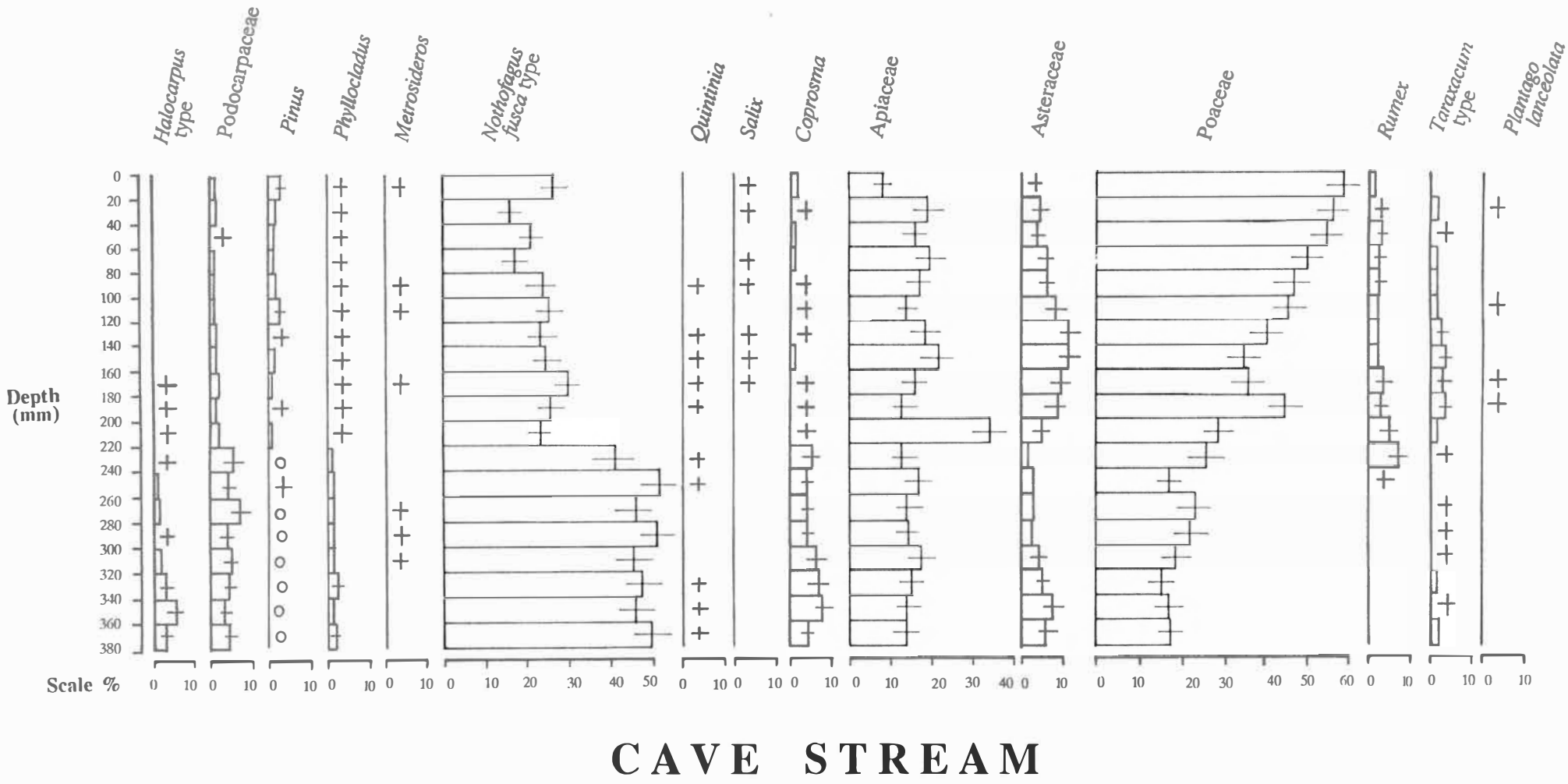


Figure 5.4 Pollen diagram from Cave Stream (site AL), Canterbury. The monolith was taken from a bog in an open grassland scrub habitat. The pollen sum is based on all terrestrial taxa which reached a value of at least 1% in any one level. (+ = trace, less than 1%; 0 = observed after the count).

7. The occurence of *Rumex*, *Taraxacum* and *Plantago lanceolata* after what appears to have been a major fire.

8. The category Podocarpaceae includes *Dacrydium cupressinum*, *Prumnopitys*, *Podocarpus totara* type which were present in trace amounts to 2%. They show a decrease after the fire.

The adventive plants; *Pinus*, *Plantago lanceolata*, *Salix*, *Rumex* and *Taraxacum* type as well as fire, are important indicators of European settlement of the area.

5.6.4 Statistical Analyses

The percentage data used to construct the pollen profiles were used for PCA and Cluster analysis. The results from PCA are shown in Figure 5.5. The first axis accounts for 75.6% of the total variance, and the second axis an additional 18.7% for a total variance of 94.3% on the first two axes. PCA depicts 4 major groupings: 1. Main Divide; 2. Bealey River; and 3. two groups for Cave Stream, one for the top half of the core and the other for the bottom half.

Cluster Analyses, using group average and single linkage methods show five clusters (Figure 5.6). Four grouping which puts most of the cores into the same groups as for the PCA and a fifth group composed of only one sample (the 200-220 mm level separating the pre- from post-fire position in the Cave Stream monolith).

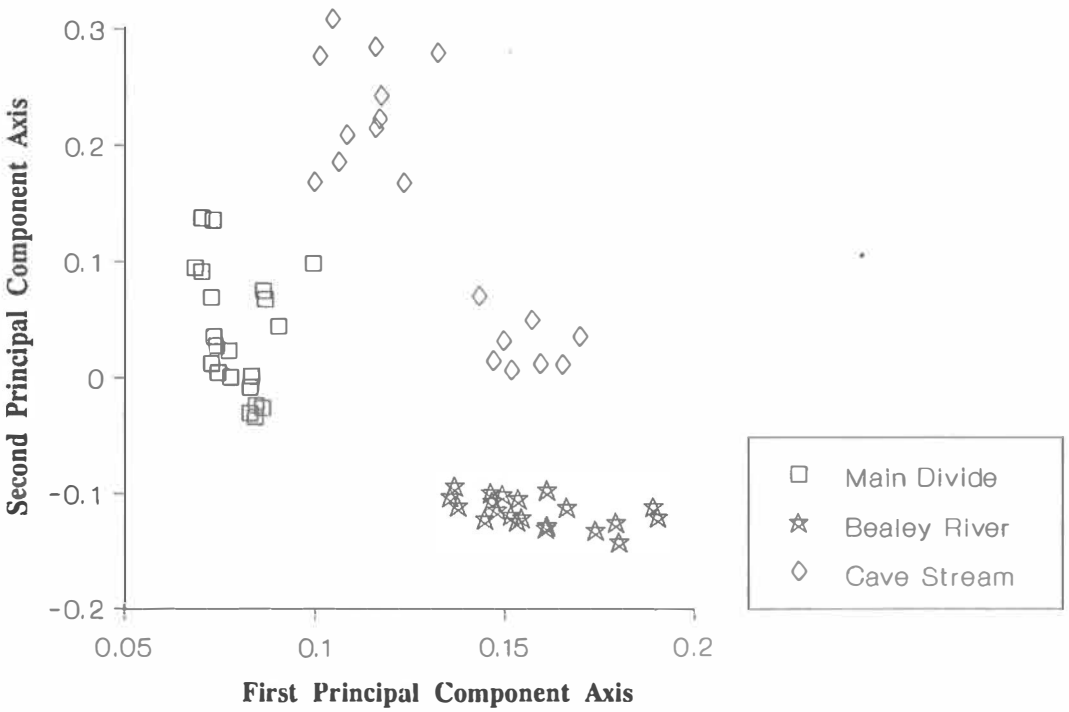


Figure 5.5 Plot of the 61 samples from the three peat profiles on the first and second principal component axes.

(b) Single linkage

Normalised Minimum Distance

0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0

B16-18
B20-22
B18-20
B22-24
B32-34
B34-36
B28-30
B24-26
B36-38
B30-32
B26-28
B12-14
B14-16
B6-8
B0-2
B38-40
B40-42
B10-12
B8-10
B4-6
B2-4
C36-38
C32-34
C30-32
C24-26
C26-28
C28-30
C34-36
C22-24
C20-22
C0-2
C16-18
C14-16
C12-14
C18-20
C10-12
C8-10
C6-8
C4-6
C2-4
M0-2
M4-6
M2-4
M18-10
M6-8
M12-14
M16-18
M14-16
M18-20
M26-28
M10-12
M20-22
M22-24
M24-26
M28-30
M40-42
M30-32
M32-34
M34-36
M36-38
M38-40

1 2 3 4 5

(a) Group average

Normalised RMS Distance

1.5 1.4 1.3 1.2 1.1 1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0

M0-0 = Main Divide Monolith
B0-0 = Bealey River Monolith
C0-0 = Cave Stream Monolith
e.g. B16-18 refers to Bealey River Monolith sample from 160-180 mm

B16-18
B20-22
B18-20
B22-24
B32-34
B34-36
B28-30
B30-32
B26-28
B12-14
B14-16
B24-26
B36-38
B6-8
B8-10
B10-12
B0-2
B38-40
B40-42
B2-4
B4-6
C22-24
C28-30
C26-28
C34-36
C30-32
C24-26
C32-34
C36-38
M12-14
M16-18
M14-16
M6-8
M8-10
M2-4
M18-20
M0-2
M4-6
M10-12
M20-22
M26-28
M22-24
M24-26
M28-30
M40-42
M34-36
M30-32
M32-34
M36-38
M38-40
C20-22
C0-2
C2-4
C4-6
C6-8
C8-10
C10-12
C18-20
C12-14
C14-16
C16-18

1 2 3 4 5

Figure 5.6 Cluster analyses of the 61 samples from the three peat profiles. Four main and one minor cluster are identified by (a) Group average at a root mean square (RMS) distance of 0.7; and (b) single linkage before the onset of chaining.

5.6.5 Comparison of surface transect with the peat monoliths

Numerical analysis was performed on a combined data set (excluding the wet site taxa and ferns ('nwf')) composed of the surface transect and all three peat monoliths. Both the Principal Components Analysis and the Cluster analysis were preformed. Comparison of modern pollen assemblages with peat profiles has been done successfully in several North American studies. Lichti-Federovich and Ritchie (1968) and Ritchie and Yarranton (1978) compared the pollen spectra from 136 superficial lake sediments with fossil pollen profiles to interprete the change in late-Quaternary vegetation in the western interior of Canada. Webb (1973) used PCA to compare modern with presettlement pollen in southern Michigan. Birks (1976) using numerical methods and modern surface samples interpreted vegetation history at Wolf Creek, central Minnesota. Davis *et al.* (1975) compiled modern pollen data from 406 surface lake sediments and these were a major source of evidence for vegetational interpretation at Moulton Pond, Maine over the past 14,000 years.

The results of the PCA are shown in Figure 5.7. The first axis accounts for 60.9 percent of the total variance, and the second axis accounts for an additional 30 percent. The Bealey monolith clusters around site N, the Main Divide monolith groups near the subalpine sites (K, L and M) and Cave Stream monolith splits into two groups; the top half of the profile (post fire) grouping with the eastern scrub/grassland sites (U, V and AD) and the bottom half of the profile grouping with the beech forest site (R).

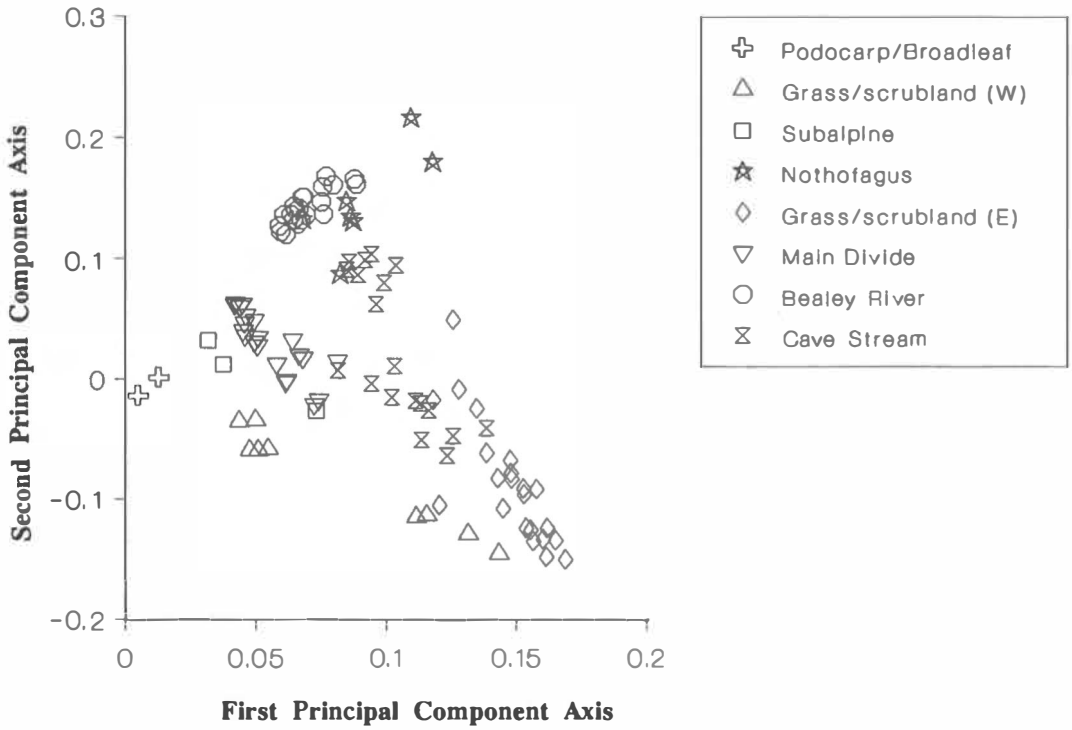


Figure 5.7 Plot of the 43 surface samples and the 61 samples from the three peat profiles on the first and second principal component axes.

At a normalised root mean square distance of 0.7, group average linkage identified 8 clusters (Figure 5.8a).

Cluster 1 includes the Bealey River monolith with the beech forest surface sample from that site (N), then three more beech forest sites (O, P and Q) join on. The bottom half of the Cave Stream profile then joins on followed by the scrubland site (AK) near Cave Stream and the remaining beech forest sites (R, S and T).

Cluster 2 includes the Main Divide monolith and the three subalpine sites. There is a slight difference between the top and bottom half of the profile. The surface sample (site K) from that location joins with the top two sections from the monolith.

Cluster 3 includes the samples from the Westland coastal site.

Cluster 4 includes the podocarp/broadleaved forest site (C) and the western scrubland site (B).

Cluster 5 includes the remaining west coast scrubland sites (I and J).

Cluster 6 includes the top half (post fire) of the Cave Stream profile with the eastern scrub/grassland sites from Horrible bog (sites U and V) and St Bernard (site AD).

Cluster 7 includes all the remaining grass/scrubland sites.

Cluster 8 single site H.

Before the onset of chaining, single linkage depicts 4 groups (Figure 5.8b)

Group 1 includes the Bealey River profile and all the beech forest sites except site R.

Group 2 contains the bottom half of the Cave Stream profile.

Group 3 contains 3 subgroups, the top half of the Cave Stream profile (post fire), the 3 scrub/grassland sites (U, V, & AD) which join at the same distance to the majority of the grassland sites. (N.B. The sample taken from the the 200-220 mm depth in the Cave Stream monolith joins onto the third group much later).

Group 4 contains the Main Divide profile and the three subalpine sites.

The numerical methods all produce similar clusters and groupings from the combined data set and the profiles group with appropriate modern surface samples. There are disadvantages and limitations of the comparative approach (see Birks and Birks 1980). The two main shortcomings are:

1. There may not be a modern equivalent to a past vegetation assemblage.

(b) Single linkage

Normalised Minimum Distance

0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0

B16-18
B20-22
B32-34
B34-36
B28-30
B18-20
B22-24
N
B24-26
B36-38
B30-32
B26-28
B12-14
B14-16
B6-8
B0-2
B38-40
B40-42
B8-10
B10-12
B2-4
B4-6
O
Q
P
S
T
C26-28
C28-30
C24-26
C30-32
C32-34
C36-38
C34-36
C22-24
C2-4
C4-6
C6-8
C8-10
C10-12
C18-20
C12-14
C14-16
C16-18
AI
AJ
Y
AH
AN
AC
X
AE
W
Z
AA
AB
AL
AG
AM
AF
AO
E
D
AD
C0-2
U
V
F
C20-22
G
AK
M10-12
M20-22
M22-24
M24-26
M26-28
M30-32
M32-34
M34-36
M36-38
M38-40
M40-42
M28-30
M12-14
M16-18
M14-16
M18-20
M6-8
M8-10
M2-4
M4-6
M0-2
K
L
M
AP
R
C
A1
A2
B
J
I
H

1
2
3
4

(a) Group average

Normalised RMS Distance

1.6 1.5 1.4 1.3 1.2 1.1 1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0

M0-0 = Main Divide Monolith
B0-0 = Bealey River Monolith
C0-0 = Cave Stream Monolith
e.g. B16-18 refers to Bealey River Monolith sample from 160-180 mm
A - AP = Surface Transect Sites

B16-18
B20-22
B18-20
B22-24
B34-36
B32-34
B28-30
N
B30-32
B12-14
B14-16
B26-28
B24-26
B36-38
B6-8
B8-10
B10-12
B38-40
B0-2
B40-42
B2-4
B4-6
O
Q
P
C36-38
C32-34
C24-26
C30-32
C34-36
C28-30
C26-28
C22-24
AK
R
S
T
M10-12
M20-22
M26-28
M24-26
M22-24
M30-32
M32-34
M36-38
M38-40
M34-36
M40-42
M28-30
M
L
K
M0-2
M4-6
M2-4
M8-10
M6-8
M12-14
M16-18
M14-18
M18-20
A1
A2
B
C
I
J
C2-4
C4-6
C6-8
C8-10
C10-12
C18-20
C12-14
C14-16
C16-18
C0-2
AD
U
V
C20-22
Y
AH
AN
AC
AI
AJ
X
AE
D
E
W
Z
AG
AO
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Figure 5.8 Cluster analyses of the 43 surface samples with the 61 samples from the three peat profiles. (a) Group average identified 8 groups at a root mean square (RMS) distance of 0.7. (b) Single linkage identified 4 groups before the onset of chaining.

2. A particular pollen spectrum can be derived from two or more quite different vegetation types.

5.7 DISCUSSION

5.7.1 Main Divide

The monolith was too young to be radiocarbon dated, but using the first occurrence of *Pinus* at 240 mm and *Salix* at 220 mm as indicators of the influence of European introduction of these species to the region (about 1870 A.D.), the bottom of the monolith was dated to approximately 150 yrs B.P..

The percentages of *Dacrydium cupressinum* and *Prumnopitys* remain unchanged. There is also no significant change in the local podocarps, *Halocarpus* and *Podocarp totara* type (including *Podocarpus hallii* which grows in Westland and up the Otira Gorge and *Podocarpus nivalis* which grows near the site).

Nothofagus remains relatively constant with a minor decrease in the top 80 mm. As beech forest dominates only 500 m to the east it is assumed that the majority of the pollen is derived from that area although some could have originated in the Taramakau and Otira valleys in Westland.

Dracophyllum, which is a major component of the subalpine scrub, is represented in only trace amounts to 2% values.

The introduction of European grasses and weeds to the area was probably accidental, caused by opening up of habitats and carriage of seed during road construction and by the droving of sheep and cattle over the pass to Westland since 1866 (Burrows 1974). The fire in 1890 may have aided the spread of the introduced species. Only Poaceae shows a significant quantitative change during the period of deposition recorded by pollen in the peat. The increase of grass at the 180-200 mm level may be due to expansion of tussock grassland after the 1890 fire (Cockayne & Calder 1932).

The Principal Components Analysis suggests a minor separation at the 180-200 mm level into two groups (before and after the increase in grass pollen percentage). This grouping is depicted in the group average cluster analysis, but not by the single linkage method.

The comparison with the surface samples shows that the profile groups with the three modern samples from Arthur's Pass (K, L and M). Group average depicts a split in the profile with site K grouping with the top portion and L and M with the bottom portion. Single linkage has the

three modern samples joining the group after all the profile has grouped. Overall the surface samples reflect the past vegetation as shown in the profile.

5.7.2 Bealey River

The most striking feature of this pollen profile is the dominance of beech with minor fluctuations. These minor fluctuations in the beech percentage through time, may be due to:

1. The life span of *Nothofagus solandri* var. *cliffortioides* (approximately 300 years) which tends to replace itself in cyclic fashion (Wardle 1963). The age of the profile spans more than that, therefore there would be death and replacement, over time, of individuals due to wind-throw, snow-break and insect damage by *Proteodes carnifex* (pinhole borer) (Wardle 1970d) around the site and its gradual regrowth;

2. Each level represents approximately 15-20 years, and as such may reflect periodic flowering (major episodes approximately once each ten years) or minor episodes every three years (Wardle 1970c);

The only taxon to show an increase during the time span represented is *Lepidothamnus*, while all the other taxa remain constant. Increased *Lepidothamnus* could be a response to the site opening up due to any or all of the above. It seems more likely to be the result of a local change in site conditions, e.g. slight drying.

Principal Components Analysis indicates that this site is the most stable of the three. Most of the variation is caused by the changes in the beech percentage. The cluster analyses indicate a similarity between the top and the bottom of the core.

Today, the site is similar to what it must have been like 500 years ago. There is no major evidence (other than trace amounts of *Pinus* which will have originated many kilometres away) of disturbance by human activity during this time. The result from the modern surface samples confirms this.

5.7.3 Cave Stream

The removal of some forest and increase, then removal, of scrub and tussock grassland began with settlement of the area by European sheep farmers, beginning in 1857 (McLeod & Burrows 1977). This is indicated by the presence of microscopic charcoal at 220-380 mm depth in the monolith and the decrease of *Halocarpus* and *Coprosma*. Most of the burning in the Craigieburn

area was probably of scrub and tussock, but in 1897 beech forest was removed from some of the low lying areas (Molloy 1977). This is shown in the pollen diagram by a 25% decrease of *Nothofagus*.

The increase of *Pinus* and the appearance of *Salix* indicate the planting of these taxa by the nearby runholders at Castle Hill, Flock Hill and Grasmere by 1870. *Taraxacum* and *Rumex* were introduced (probably accidentally) at the same time. Paintings and photographs of the district by J. Enys, done between 1870 and 1874, show pines at Grasmere and Flock Hill and willows at Castle Hill (Dr. C.J. Burrows pers comm).

The monolith was too young to be radiocarbon dated, but the presence of microscopic charcoal from 220-380 mm, *Pinus* (240-260 mm) and *Salix* pollen (180-200 mm), suggests that the bottom of it should be about 140 years old.

Asteraceae pollen is produced by both herbaceous and shrub taxa. The initial decline and recovery is probably due to the removal of *Cassinia fulvida*, its replacement by herbaceous taxa then the re-establishment of *Cassinia*.

The increase in Poaceae is due firstly to the expansion of native grasses (*Festuca* and *Poa*), then from about 1890 onwards, to the introduction and establishment of *Agrostis capillaris* and *Anthoxanthum odoratum*. The apparent decline of Podocarpaceae pollen, (almost certainly derived from distant sources) is an artefact arising from the increase of the amount of pollen produced by the introduced grasses.

PCA splits the 19 samples into two major groups; 1. the bottom half, which is the time in which the site and the immediate area were subjected to intensive modification by fire; and 2. the top half of the profile (post fire). Cluster Analysis forms the same two groups as for PCA, as well as separating the 200-220 mm level into a group of its own. This level represents the time immediately following the burning of the site. The dominant feature of this level in the large increase of Apiaceae pollen which is a response to burning (Dr. N.T. Moar pers comm).

The pollen profile suggests that though there were numerous fires in the immediate area from the 1870s onwards, the fire of 1897 was located either on or surrounding the present site. It appears to have destroyed the beech forest and scrub, which was replaced by grassland. Unfortunately the monolith was not deep enough to record the vegetation at the site prior to European burning of the area.

The modern surface comparison supports these conclusions. The results from the PCA and cluster analysis, both group average and single linkage, suggest that the top half of the profile is similar to modern samples from sites U, V and AD.

5.8 CONCLUSION

Both the Main Divide and Bealey River monoliths, indicate that the European settlement (since 1857) has not greatly affected deposition of *Dacrydium cupressinum* and *Prumnopitys* pollen, although during this time there has been extensive clearance of forest to the west and south west of Lake Brunner. This may be due to the fact that the majority of the pollen deposited on the Main Divide originates from the Otira valley, and not from the Taramakau valley further to the west.

The increased percentage of grass pollen on the Main Divide site and the presence of *Pinus*, *Salix* and *Taraxacum* pollen are the only indicators of European influence at this site. At Bealey River the only indicators are *Pinus* and *Taraxacum*. Of the three monoliths, Cave Stream is the most affected by European settlement which resulted in the removal of beech forest and scrubland by fire and their replacement by grassland, probably originally native *Festuca* and *Poa* but now dominated by introduced taxa mainly *Agrostis capillaris* and *Anthoxanthum odoratum*.

The Main Divide and Bealey River monoliths contain pollen which was clearly derived from both the local and the regional vegetation, whereas the Cave Stream monolith has always been dominated by pollen derived from the local vegetation.

The positive outcome from combining the surface sample data with that of the peat profiles encourages the use of this technique in evaluating pollen profiles. This is a preliminary result; however it agrees well with studies done in North America (Lichti-Federovich and Ritchie 1968; Webb 1973; Davis *et al.* 1975; Birks 1976; Ritchie and Yarranton 1978;).

CHAPTER 6
SUMMARY

The primary purpose of most palynological studies in New Zealand has been to reconstruct the composition of the vegetation during the Quaternary period. Until the work of Moar (1970, 1971), Pocknall (1978, 1980, 1982) and McGlone (1982), little was known about the modern pollen deposition. In turn, this limited the accuracy with which pollen spectra could be interpreted. Nevertheless, many uncertainties remained about the relationship between pollen fallout and the contributing vegetation. The present study was undertaken to amplify and clarify this relationship.

The study area extended on a transect from the Westland lowland into the Westland Ranges, across the Main Divide of the Southern Alps and through the mountains to the eastern edge of the Canterbury Ranges. This meant that data was gathered in the high rainfall region of Westland, with its complex multi-storied evergreen forest, through subalpine scrub, grassland and bog at Arthur's Pass (also a high rainfall region) and the simple-structured beech forest of western Canterbury, then under a rapidly diminishing annual rainfall, to the dry grassland and scrub of the eastern Canterbury Ranges. The influence of the prevailing westerly windflow interacting with the complex terrain was expected to profoundly influence the transport of pollen and spores.

6.1 TRAP RESULTS

One year of pollen deposition was collected. The results showed that pollen accumulation rates differed over the seasons and that redeposition was not a major component of the annual pollen accumulation. The highest annual accumulation occurred not far west of the Main Divide at Barrack Creek but there was a special reason for this, namely the concentration of *Metrosideros* pollen thought to be from bee faeces. The lowest accumulation was in the beech forest presumably because the dominant taxon (*Nothofagus solandri* var. *cliffortioides*) only had a minor flowering episode. The PAR reflect the main vegetation types at all the sites. The data from these traps reveal that the locally derived pollen is very well represented while the regionally derived pollen is relatively poorly represented. Traps in other locations caught roughly similar amounts of pollen; the range of number of grains cm^{-2} $site^{-1}$ was 1959 (beech forest) to 34261 (Barrack Creek) with a mean value of 12200.

The significant points from the results are:

1. The broadleaved angiosperm trees (*Metrosideros*, *Quintinia* and *Weinmannia*) have high accumulation rates near their source, which declines rapidly over a few hundred metres.

2. Beech pollen has a higher accumulation in the grasslands than in the forest.

3. The herbaceous taxa were important only in grassland sites.

4. Most pollen deposition occurs during the main flowering season for each taxon.

5. Redeposition is not a major component of the annual pollen deposition.

6.2 MOSS AND LICHEN POLSTERS RESULTS

The moss and lichen polsters were collected from the range of main vegetation types represented on the transect. The pollen spectra were dominated primarily by local taxa. However, there was a much higher representation of regional pollen at the Westland coastal site and sites on and near the Main Divide than in all the other sites. This resulted from:

1. At site A, lack of any continuous vegetation and the position of the site (i.e. no vegetation to the west).

2. At the Main Divide sites (K, L and M) low pollen production of the dominant entomophilous taxa. Therefore, the regional pollen deposition was not 'swamped' by the local taxa. (N.B. the regional pollen derived by upslope transport does not mask the local deposition).

6.3 'ABSOLUTE' POLLEN COUNTS

The 'absolute' pollen study (applied to moss polsters at certain sites) confirmed or supported several of the patterns observed in the pollen trap study.

1. The high PAR for *Metrosideros* at Barrack Creek were confirmed by high concentrations in the moss polster probably originating from bee faeces.

2. The pollen traps showed a higher PAR for beech pollen in the grassland sites to the east of the beech forest. However, concentration values of beech from the moss polster were similar in both the forest and grassland sites.

3. The pollen concentration study shows that the upslope transport of pollen did not involve an increase in pollen deposition, as would be expected from Tauber's (1965) rainout component, but apparent high levels of lowland taxa result from the low local pollen production and deposition of the predominately entomophilous vegetation.

4. This study also demonstrated that regional pollen was masked by the local dominant taxa at all sites except those on the Main Divide.

Despite the paucity of important 'indicator' pollen taxa, the numerical methods (PCA and Cluster analysis) recontructed the vegetation types from their pollen spectra. The four main taxa (*Dacrydium cupressinum*, *Metrosideros*, *Nothofagus fusca* type and Poaceae) varied sufficiently between vegetation types to permit them to be distinguished. Minor pollen types were not important.

6.4 PEAT MONOLITH STUDIES

Time scales for the peat profiles were established by radiocarbon-dating (Bealey River) and by adventive pollen types (*Pinus*, *Salix* and *Plantago lanceolata* and to a lesser degree, *Rumex* and *Taraxacum*) which indicated European settlement. The dates of first planting of pines and the entry of adventive weed taxa such as *Plantago lanceolata*, *Rumex acetosella* and *Hypochoeris radicata* are known within about a decade.

The Main Divide profile showed a steady contribution by various Westland tree taxa during the past 150 years. At Bealey River, beech dominance has been constant for the last 500 years. No major change in the vegetation has occurred at this location. The profile also showed an accumulation of podocarp pollen from Westland. Cave Stream accurately reflected the effects of European settlement in the area. The bottom half of the profile recorded the burning in the area, the middle level (200-220 mm), burning on the site in 1897 and the top half recorded the changes from fire induced tussock grassland to adventive grassland as a consequence of farming in the area.

Main Divide and Bealey River peat profiles recorded both the local as well as the regional pollen deposition. The profile at Cave Stream recorded predominately the local and extralocal vegetation. This resulted from the lower local pollen deposition at Main Divide and Bealey River.

The positive developments from comparison of surface samples with the peat profiles by means of numerical methods, confirmed the desirability of using comparative methods, to assist in their interpretation. This method has been used successfully in several North American studies (e.g. Webb 1973; Ritchie and Yarranton 1978).

It has always been difficult to match pollen spectra from sediments with modern spectra from moss polsters and traps and, in turn, to relate these to the contributing vegetation. The results described here identify specific differences between the data from each of the different sources. They

provide a much sounder base, than has hitherto been available for assessing the various relationships. The least satisfactory aspect of any such studies is the lack of some means of relating the relative abundances of various taxa in the vegetation to their proportions in the pollen spectra. Because of the great array of variable factors which could contribute to the ultimate composition of the pollen deposition perhaps the assessment of this vegetation/pollen deposition relationship can never be better than qualitative.

6.5 FURTHER RESEARCH

The results from this study suggest several areas which require further study:

1. Pollen trapping should be done for a five to ten year period and for a greater variety of vegetation types. The problems encountered mainly resulted from sabotage by both nature (river floods and Keas) and humans.

2. Expansion of the number of surface samples to incorporate as many different main vegetation types and topographic situations as possible then compare these with peat profiles using numerical methods such as Principal Components Analysis and Cluster Analysis.

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APPENDIX A

Surface Transect raw pollen counts.

Site	A1	A2	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
Dacrydium cupressinum	28	19	312	167	16	16	20	1	1	3	5	2	2	63	19	27	5	2	11	7	7	4	3	2	2	1	4
Dacrycarpus dacrydioides	6	2	2	5	2	3	-	3	2	1	1	2	9	14	3	4	1	1	-	-	1	2	2	-	-	-	-
Halocarpus type	3	-	-	-	-	1	-	-	-	-	1	6	55	6	38	26	5	9	152	36	1	1	-	-	-	-	-
Lagarostrobos colensoi	7	4	-	-	1	-	-	-	-	-	-	2	4	4	5	-	-	-	-	-	-	-	-	-	-	-	-
Lepidothamnus	-	-	-	-	-	-	-	-	-	1	-	16	32	35	31	13	-	73	1	-	-	-	-	-	-	-	-
Podocarpus totara type	2	4	3	2	4	1	1	7	-	4	5	26	23	28	28	7	6	16	9	3	2	3	11	-	2	1	2
Prumnopitys (total)	11	8	14	35	4	5	8	10	2	3	1	54	86	110	81	17	7	15	2	3	4	4	2	-	1	2	-
Pinus	144	98	12	44	9	11	62	9	1	2	8	3	11	28	3	13	6	4	14	2	4	24	18	4	6	13	2
Phyllocladus	3	2	5	2	74	10	6	32	4	-	6	17	39	27	23	22	114	23	30	5	11	-	2	5	-	-	13
Cupressaceae	-	-	-	3	1	-	4	2	-	2	-	-	1	4	5	-	1	2	-	-	12	-	1	1	-	1	-
Aristotelia	6	-	-	10	13	2	3	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-
Ascarina	13	4	3	2	2	1	-	-	-	1	2	-	4	2	2	-	1	1	-	-	-	-	-	-	-	-	1
Alnus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Betula	-	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	1	1	-
Casuarina	-	-	-	2	-	-	-	1	-	-	-	-	3	-	1	-	-	-	3	1	-	-	-	-	-	-	-
Hoheria	-	-	-	-	-	-	-	-	4	3	19	-	-	3	2	1	1	-	-	-	-	1	-	-	-	-	-
Leycesteria	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Myrtaceae	3	5	-	3	3	3	1	-	-	-	-	-	-	2	1	1	-	-	-	-	-	-	-	-	-	-	-
Metrosideros	7	23	42	51	11	5	15	5	414	221	124	11	6	17	3	8	10	9	1	-	5	-	2	-	-	1	-
Muehlenbeckia	2	-	-	-	1	-	21	-	23	9	13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nothofagus fusca type	31	12	8	12	15	7	8	16	5	2	7	4	72	69	318	276	404	347	251	531	508	156	179	64	32	65	96
Nothofagus menziesii	-	-	-	-	1	-	-	-	1	-	-	1	1	3	2	2	3	1	-	7	3	1	3	3	1	1	5
Pseudowintera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Quintinia	9	2	14	24	16	5	4	2	72	52	5	3	8	5	3	5	2	5	-	2	1	-	-	-	-	-	-
Schefflera	2	4	-	3	4	-	-	-	3	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Salix	1	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	1	-	1	-	1	-	1	-	6	-	-
Weinmannia	5	-	9	31	13	1	5	9	28	16	21	-	3	6	2	1	2	3	1	-	1	-	-	-	-	-	-
Coprosma	18	14	7	12	13	4	9	2	6	30	10	36	20	38	16	11	4	12	5	5	10	47	10	2	7	5	4
Discaria	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	2	2	3	-	11	3	-
Epacridaceae	1	-	-	2	1	-	-	-	-	-	3	1	6	6	1	2	2	2	-	4	-	1	2	-	-	-	-
Fuchsia	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hebe	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Leptospermum	-	-	3	-	-	-	-	-	-	-	-	-	1	-	-	3	38	4	-	-	-	36	16	2	-	-	-
Myrsine	11	7	2	58	2	2	3	2	-	4	1	-	6	6	1	-	2	1	-	-	-	-	2	-	-	-	-
Pimelea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Acaena	2	-	-	-	-	1	-	-	-	-	4	-	-	-	1	-	-	-	-	-	-	-	-	-	1	-	-
Apiaceae	7	10	5	2	7	6	22	91	21	23	9	3	7	5	-	-	2	-	3	2	-	6	1	7	8	-	4
Asteraceae	10	1	1	1	2	1	2	3	13	4	66	12	7	17	3	-	1	3	1	3	1	8	9	7	-	5	5
Bulbinella	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Caryophyllaceae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Centrolepidaceae	2	-	1	-	-	-	-	-	-	-	-	1	124	6	11	-	-	19	-	-	-	-	-	-	-	-	-
Chenopodiaceae	2	-	-	-	-	-	-	-	-	-	-	-	1	2	1	-	-	-	-	-	-	-	-	-	-	-	-
Coriaria	2	2	-	1	5	-	8	-	32	87	19	4	1	5	2	3	1	4	2	-	-	1	-	-	-	-	-
Cruciferae	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cyperaceae	26	98	2	4	1	1	12	3	-	-	1	234	14	55	18	193	2	43	102	62	34	51	114	27	7	72	84
Donatia	-	-	-	-	-	-	-	-	-	-	-	-	2	5	4	-	-	-	-	-	-	-	-	-	-	-	-
Drosera	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Drosera arcturi	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Gentiana	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	2	-	-	-	-	-	-	-	-	-
Gunnera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	4	-	-	-	-
Haloragis	6	8	-	-	-	-	-	5	-	-	-	-	-	-	2	-	-	-	3	-	-	6	-	293	-	20	17
Papilionaceae	4	5	-	-	2	-	8	-	5	-	20	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Phormium	1	2	-	-	-	-	-	-	3	2	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Plantago (indigenous)	2	3	-	-	-	-	-	-	-	-	-	2	-	4	-	-	-	-	-	-	-	-	2	-	-	1	-
Plantago lanceolata	98	90	-	1	1	1	2	33	-	-	1	2	-	2	1	2	2	-	-	-	-	2	1	-	14	-	1
Poaceae	143	165	181	41	434	518	372	402	40	203	207	138	47	82	27	47	48	67	98	23	88	266	270	266	575	477	389
Ranunculus	-	6	-	-	1	17	2	41	4	4	8	-	-	3	1	3	-	-	-	-	-	-	-	-	-	1	-
Rosaceae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Rumex	35	29	-	-	18	49	-	1	-	6	18	-	3	7	2	5	7	2	-	1	-	4	4	3	6	6	4
Taraxacum	2	8	5	1	3	1	32	7	13	13	102	1	1	22	1	3	2	1	2	-	-	3	13	2	15	3	1
Typha	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	65
Voila	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wahlenbergia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unidentified	1	3	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-
Myriophyllum	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Monolete (total)	19	15	5	55	22	11	38	42	1	2	4	20	18	26	9	8	13	8	5	1	1	70	16	7	6	11	1
Cyathea	13	16	10	28	38	18	25	-	1	1	2	14	10	18	2	10	5	9	4	1	2	1	-	-	-	3	1
Dicksonia fibrosa	3	7	-	4	5	-	5	-	-	-	-	-	2	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Dicksonia squarrosa	8	8	7	13	11	2	-	-	1	1	1	1	-	-	2	-	-	1	-	1	-	-	-	-	-	-	-
Pteridium	-	4	-	3	5	-	4	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-
Trilete	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
Lycopodium	-	2	-	6	2	-	-	1	-	-	-	7	6	6	15	5	1	2	-	-	-	-	3	5	-	4	4
Total pollen	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700

APPENDIX A (continues)

Surface Transect raw pollen count

Site	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	Total Sum	Total %
Dacrydium cupressinum	5	8	2	7	2	4	-	1	1	1	1	2	10	-	2	-	813	3
Dacrycarpus dacrydioides	2	1	-	1	1	-	-	1	-	1	2	1	-	-	1	1	78	0
Halocarpus type	-	-	-	1	-	-	-	-	-	-	-	-	4	-	-	-	345	1
Lagarostrobos colensoi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	27	0
Lepidothamnus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	202	1
Podocarpus totara type	5	2	1	1	4	3	2	1	1	-	3	2	3	-	3	1	232	1
Prumnopitys (total)	-	-	-	3	1	-	-	3	-	-	2	3	3	-	1	1	506	2
Pinus	10	19	3	5	5	15	14	16	3	6	29	28	21	17	22	16	794	3
Phyllocladus	6	2	5	22	1	1	-	3	4	3	4	-	1	2	5	2	554	2
Cupressaceae	-	-	-	-	-	2	-	1	-	-	-	-	4	-	-	-	47	0
Aristotelia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	37	0
Ascarina	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	40	0
Alnus	-	-	-	1	-	-	-	-	-	-	1	-	-	-	1	2	5	0
Betula	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	6	0
Casuarina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	0
Hoheria	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34	0
Leycesteria	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0
Myrtaceae	-	-	1	-	1	-	-	-	-	2	-	-	-	-	2	-	28	0
Metrosideros	3	-	-	-	-	3	1	-	2	-	1	-	-	-	-	-	1001	3
Muehlenbeckia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	69	0
Nothofagus fusca type	108	88	52	165	43	88	58	54	58	49	312	138	119	45	64	32	5012	17
Nothofagus menziesii	4	-	1	-	2	-	-	1	1	2	-	-	1	1	-	2	54	0
Pseudowintera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0
Quintinia	-	-	1	-	-	2	1	-	-	-	-	-	-	-	-	-	243	1
Schefflera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19	0
Salix	-	-	1	-	-	1	-	36	-	-	1	1	-	-	5	2	60	0
Weinmannia	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	158	1
Coprosma	3	16	20	11	6	9	6	3	6	4	9	6	10	16	-	7	489	2
Discaria	2	2	2	-	3	3	-	-	-	2	-	-	-	-	1	-	38	0
Epacridaceae	-	-	-	-	-	-	1	-	-	-	-	-	1	-	-	1	37	0
Fuchsia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0
Hebe	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	0
Leptospermum	-	4	1	-	-	-	-	-	-	-	2	-	-	-	1	-	111	0
Myrsine	1	-	1	-	-	-	-	-	-	-	-	-	1	-	1	-	114	0
Pimelea	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	0
Acaena	-	-	-	-	-	-	-	-	-	2	-	-	-	-	3	-	14	0
Apiaceae	3	-	15	20	12	3	-	-	3	9	15	4	2	2	20	2	361	1
Asteraceae	17	3	2	15	-	2	1	-	7	7	12	15	5	4	8	6	290	1
Bulbinella	-	-	-	-	-	-	-	-	-	1	-	-	-	-	11	4	16	0
Caryophyllaceae	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	0
Centrolepidaceae	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	168	1
Chenopodiaceae	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	1	9	0
Coriaria	1	-	-	-	-	-	-	-	-	-	-	-	1	2	-	101	284	1
Cruciferae	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	11	0
Cyperaceae	48	87	4	25	1	94	112	71	51	108	-	68	59	31	86	69	2174	7
Donatia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	0
Drosera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0
Drosera arcturi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	0
Gentiana	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	8	0
Gunnera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	0
Haloragis	23	105	28	95	-	2	151	18	-	-	-	5	76	-	-	-	863	3
Papilionaceae	-	-	-	-	-	-	-	1	3	-	-	-	4	-	-	-	54	0
Phormium	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18	0
Plantago (indigenous)	1	-	-	-	-	2	-	-	-	-	-	-	-	3	1	-	21	0
Plantago lanceolata	1	1	-	-	-	1	-	1	-	-	-	2	4	-	4	1	269	1
Poaceae	413	325	534	306	613	354	272	477	504	445	261	411	344	530	427	311	12141	40
Ranunculus	-	-	-	-	-	-	-	-	-	-	-	-	3	11	-	-	105	0
Rosaceae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0
Rumex	4	2	1	-	2	5	4	4	1	2	18	5	12	10	6	8	294	1
Taraxacum	3	2	10	8	1	32	11	2	41	36	9	6	4	11	16	1	450	1
Typha	11	11	1	-	-	60	56	-	1	-	-	-	2	-	-	-	207	1
Voila	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	2	0
Wahlenbergia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	2	0
Unidentified	-	-	5	-	-	1	-	-	-	-	-	-	-	-	1	7	21	0
Myriophyllum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0
Monolete (total)	14	6	9	13	-	7	4	6	4	13	9	3	5	13	5	116	661	2
Cyathea	1	-	-	-	-	-	2	-	-	-	4	-	-	-	-	-	239	1
Dicksonia fibrosa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	27	0
Dicksonia squarrosa	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	58	0
Pteridium	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24	0
Trilete	-	-	-	-	1	2	1	-	-	2	-	-	-	-	-	4	16	0
Lycopodium	4	10	-	-	-	-	3	-	8	-	3	-	-	1	-	1	99	0
Total pollen	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	30100	100

APPENDIX B

Surface transect, percentage data. Pollen sum as for Figure 4.1.

	A1	A2	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP
Dacrycarpus dacrydioides	1	+	+	1	+	+	-	+	+	+	+	+	2	2	+	1	+	+	-	-	+	+	+	-	-	-	-	+	+	-	+	+	-	-	+	-	+	+	+	-	-	+	+
Dacrydium cupressinum	5	4	46	29	3	2	3	+	+	+	1	5	12	3	4	1	+	2	1	1	1	1	+	1	+	1	-	1	2	+	1	+	1	-	+	+	+	+	+	2	-	+	-
Halocarpus type	+	-	-	-	-	+	-	-	-	-	+	1	11	1	6	5	1	1	26	6	+	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	1	-	-	-
Lagarostrobos colensoi	1	1	+	-	+	-	-	-	-	-	-	+	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lepidothamnus	-	-	-	-	-	-	-	-	-	+	-	4	6	6	5	3	-	12	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Podocarpus totara type	+	1	+	+	1	+	+	1	-	1	1	6	4	5	4	1	1	3	2	+	+	1	2	-	+	+	+	1	+	+	+	1	1	1	+	+	-	+	+	1	-	1	+
Prumnopitys (total)	2	2	2	6	1	1	1	2	+	+	+	13	17	19	13	4	1	2	+	+	1	1	+	-	+	+	-	-	-	-	1	+	-	-	1	-	-	+	+	1	-	+	+
Pinus	23	19	2	8	1	2	10	1	+	+	1	3	2	5	+	3	1	1	2	+	1	4	3	1	1	2	-	2	4	+	1	1	3	4	3	+	1	4	4	4	3	4	3
Phyllocladus	+	+	8	13	2	1	+	+	1	-	1	4	8	5	4	5	17	4	5	1	2	-	+	1	-	-	2	1	+	1	4	+	+	-	1	1	1	1	-	+	+	1	+
Cupressaceae*	-	-	-	1	+	-	1	+	-	+	-	-	+	1	1	-	+	+	-	-	2	-	+	+	-	+	-	-	-	-	-	-	+	-	+	-	-	-	-	1	-	-	-
Aristotelia*	1	-	-	2	2	+	+	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ascarina*	2	1	+	+	+	+	-	-	-	+	+	-	1	+	+	-	+	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-
Hoheria*	-	-	-	-	-	-	-	-	1	+	3	-	-	1	+	+	+	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Metrosideros	1	4	6	9	2	1	2	1	59	32	18	3	1	3	+	2	1	1	+	-	1	-	+	-	-	+	-	1	-	-	-	-	1	+	-	+	-	+	-	-	-	-	-
Muehlenbeckia*	+	-	-	-	+	-	3	-	3	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nothofagus fusca type	5	2	1	2	2	1	1	2	1	+	1	11	14	12	50	57	60	56	43	84	77	27	32	17	5	11	18	18	19	8	29	6	17	16	9	9	9	46	22	21	7	11	6
Nothofagus menziesii*	-	-	-	-	+	-	-	-	+	-	+	-	-	1	+	+	+	+	-	1	+	+	1	1	+	+	1	1	-	+	-	+	-	-	+	+	+	-	-	+	+	-	+
Quintinia	1	+	2	4	3	1	1	+	10	7	1	1	2	1	+	1	+	1	-	+	+	-	-	-	-	-	-	-	-	+	-	-	+	+	-	-	-	-	-	-	-	-
Schefflera*	+	1	-	1	1	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Weinmannia	1	-	1	5	2	+	1	1	4	2	3	-	1	1	+	+	+	+	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-
Coprosma	3	3	1	2	2	1	1	+	1	4	1	9	4	7	3	2	1	2	1	1	2	8	2	1	1	1	1	1	3	3	2	1	2	2	1	1	1	1	1	2	2	-	1
Discaria	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+	+	1	-	2	1	-	+	+	+	-	+	1	-	-	-	+	-	-	-	-	-	-
Epacridaceae*	+	-	-	+	+	-	-	-	-	-	+	+	1	1	+	+	+	+	-	1	-	+	+	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	+	-	-	+	-
Leptospermum	-	-	+	-	-	-	-	-	-	-	-	-	+	-	-	1	6	1	-	-	-	6	3	1	-	-	-	-	1	+	-	-	-	-	-	-	-	+	-	-	-	+	-
Myrsine	2	1	+	10	+	+	+	+	-	1	+	-	1	1	+	-	+	+	-	-	-	-	+	-	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-	+	-	+	-
Apiaceae	1	2	1	+	1	1	4	14	3	3	1	1	1	1	-	-	+	-	1	+	-	1	+	2	1	-	1	1	-	2	4	2	1	-	-	+	2	2	1	+	+	3	+
Asteraceae	2	+	+	+	+	+	+	+	2	1	10	3	1	3	+	-	+	+	+	+	+	1	2	2	-	1	1	3	1	+	3	-	+	+	-	1	1	2	2	1	1	1	1
Bulbinella*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	2	1
Coriaria	+	+	-	+	1	-	1	-	5	13	3	1	+	1	+	1	+	1	+	-	-	+	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	+	+	-	20
Papilionaceae*	1	1	-	-	+	-	1	-	1	-	3	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	1	-	-	-
Phormium*	+	+	-	-	-	-	-	-	+	+	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	+	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Plantago (indigenous)*	+	1	-	-	-	-	-	-	-	-	-	+	-	1	-	-	-	-	-	-	-	-	+	-	-	+	-	+	-	-	-	-	+	-	-	-	-	-	-	+	+	-
Plantago lanceolata	16	17	-	+	+	+	+	5	-	-	+	+	-	+	+	+	+	-	-	-	-	+	+	-	2	-	+	+	+	-	-	-	+	-	+	-	-	-	+	1	-	1	+
Poaceae	23	31	26	7	71	78	61	62	6	29	30	33	9	14	4	10	7	11	17	4	13	47	49	72	85	81	74	69	68	82	54	88	67	73	84	79	78	38	66	62	81	72	63
Ranunculus	-	1	-	-	+	3	+	6	1	1	1	-	-	1	+	1	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	-	-
Rumex	6	6	-	-	3	7	-	+	-	1	3	-	1	1	+	1	1	+	-	+	-	1	1	1	1	1	1	1	+	+	-	+	1	1	1	+	+	3	1	2	2	1	2
Taraxacum	+	2	1	+	+	+	5	1	2	2	15	+	+	4	+	1	+	+	+	-	-	1	2	1	2	1	+	1	+	2	1	+	6	3	+	6	6	1	1	1	2	3	+

+ = trace (less than 1%. Note all values rounded to the nearest 1%).

* = Not shown on Figure 4.1.

APPENDIX C

Raw pollen count for surface samples with marker Lycopodium.

Site	B	C	H	I	J	K	L	M	N	Q	R	AF	AL	AP	Total (sum)	Total %
Dacrydium cupressinum	754	172	2	5	5	17	72	31	37	11	7	10	-	2	1125	8
Dacrycarpus dacrydioides	5	-	2	2	2	2	8	5	6	1	-	1	2	-	36	0
Halocarpus type	2	1	-	1	1	1	37	8	26	9	152	-	2	-	240	2
Lagarostrobos colensoi	3	-	-	-	-	1	3	2	4	-	-	-	-	-	13	0
Lepidothamnus	-	-	-	-	-	5	23	60	49	73	1	-	-	-	211	1
Podocarpus totara type	14	5	1	11	8	14	21	38	23	16	9	2	5	3	170	1
Prumnopitys	29	35	3	4	10	36	86	106	95	15	2	6	1	2	430	3
Pinus	36	40	2	7	9	9	23	18	9	4	14	13	35	16	235	2
Phyllocladus	118	60	4	5	6	11	36	27	25	23	30	6	1	2	354	2
Cupressaceae	-	3	-	-	-	-	2	2	3	2	-	6	1	-	19	0
Aristotelia	4	-	8	8	-	-	-	-	-	-	-	-	-	-	20	0
Ascarina	6	5	4	5	4	2	3	4	1	1	-	1	-	-	36	0
Casuarina	-	1	-	-	-	-	1	1	-	-	3	-	-	-	6	0
Myrtaceae	-	-	-	-	-	-	-	1	2	-	-	-	-	-	3	0
Griselina	-	-	11	6	3	-	-	-	-	-	-	-	-	-	20	0
Hoheria	-	-	2	11	40	2	-	3	-	-	-	-	-	1	59	0
Leycesteria	-	1	-	-	2	-	-	-	-	-	-	-	-	-	3	0
Metrosideros	65	48	739	574	396	12	12	11	8	9	1	-	-	1	1876	13
Muehlenbeckia	-	65	49	36	55	-	-	-	2	-	-	-	-	-	207	1
Nothofagus fusca type	27	7	12	13	22	45	72	89	253	347	251	125	207	25	1495	11
Nothofagus menziesii	-	-	-	-	-	-	1	-	3	1	-	-	-	-	5	0
Quintinia	25	33	95	156	35	5	3	6	5	5	-	1	-	-	369	3
Salix	-	-	-	-	-	2	1	-	-	-	1	-	-	-	4	0
Schefflera	-	8	5	8	9	-	-	-	-	-	-	-	-	-	30	0
Weinmannia	12	6	100	97	118	4	4	3	3	3	1	-	-	-	351	2
Coprosma	7	18	7	61	37	35	27	42	20	12	5	37	11	14	333	2
Discaria	-	-	-	-	-	-	-	-	-	-	-	11	1	1	13	0
Epacridaceae	-	1	2	4	13	3	4	-	3	2	-	-	1	3	36	0
Fuchsia	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	0
Leptospermum	3	1	-	-	-	-	-	-	-	4	-	4	-	-	12	0
Myrsine	5	46	-	1	2	5	2	10	2	1	-	-	-	-	74	1
Acaena	-	-	-	-	-	-	-	1	1	-	-	-	-	-	2	0
Apiaceae	5	-	2	20	-	2	7	8	1	-	3	25	16	5	94	1
Asteraceae	4	4	17	6	94	24	8	18	4	3	1	7	10	4	204	1
Bulbinella	-	-	-	-	-	-	-	-	-	-	-	-	-	16	16	0
Centrolepidaceae	1	-	-	-	-	4	55	3	18	19	-	-	-	-	100	1
Chenopodiaceae	-	-	-	-	-	1	1	4	1	-	-	-	-	-	7	0
Coriaria	-	-	66	264	85	2	7	5	3	4	2	2	2	21	463	3
Crassulaceae	-	-	12	25	-	-	-	-	-	-	-	-	-	-	37	0
Cyperaceae	2	3	-	-	1	309	56	49	17	43	102	146	77	101	906	6
Donatia	-	-	-	-	-	-	2	-	7	-	-	-	-	-	9	0
Drosera arcturi	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1	0
Gentiana	-	-	1	1	2	-	1	3	-	2	-	-	-	-	10	0
Haloragis	-	-	-	-	-	-	-	-	-	-	3	6	15	-	24	0
Lotus	-	1	1	-	4	-	-	-	-	-	-	-	-	-	6	0
Papilionaceae	-	-	6	6	7	-	-	2	-	-	-	-	-	-	21	0
Phormium	-	-	2	5	-	1	-	-	-	-	-	2	-	-	10	0
Plantago (indigenous)	-	-	-	-	-	1	-	1	-	-	-	2	-	-	4	0
Plantago lanceolata	1	1	-	2	4	-	-	-	1	-	-	-	7	4	20	0
Poaceae	411	18	44	368	490	117	84	99	22	67	98	757	509	312	3396	24
Ranunculus	-	-	2	6	-	2	5	7	-	-	-	-	-	2	24	0
Rubus	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	0
Rumex	-	-	-	30	12	-	2	1	6	2	-	7	4	-	64	0
Taraxacum Type	9	3	24	42	218	-	1	8	-	1	2	50	5	5	368	3
Typha	-	-	-	-	-	-	-	-	-	-	-	83	-	-	83	1
Monolete	16	60	3	9	6	7	19	10	9	8	5	16	18	156	342	2
Cyathea	25	41	2	-	9	8	8	8	8	9	4	-	1	-	123	1
Dicksonia fibrosa	-	-	-	-	-	-	2	-	-	-	-	-	-	-	2	0
Dicksonia squarrosa	11	12	3	-	-	1	1	1	2	1	-	-	-	-	32	0
Pteridium	-	1	-	-	-	-	-	-	-	-	3	2	1	-	7	0
Lycopodium	-	-	-	-	-	9	-	5	21	2	-	2	2	4	45	0
Total pollen count	1600	700	1234	1800	1709	700	700	700	700	700	700	1330	934	700	14207	100
Exotic marker	70	392	11	26	100	249	129	254	115	211	187	94	100	161		

APPENDIX D

Mean 'absolute' concentration from one gram of moss.

Pollen/gm	B	C	H	I	J	K	L	M	N	Q	R	AF	AL	AP	Total influx	Total %
Dacrydium cupressinum	233740	9521	3945	4173	1085	1482	12112	2648	6982	1131	812	2309	0	270	280210	5
Dacrycarpus dacrydioides	1550	0	3945	1669	434	174	1346	427	1132	103	0	231	434	0	11446	0
Halocarpus type	620	55	0	835	217	87	6224	683	4906	926	17639	0	434	0	32626	1
Lagarostrobos colensoi	930	0	0	0	0	87	505	171	755	0	0	0	0	0	2447	0
Lepidothamnus	0	0	0	0	0	436	3869	5126	9246	7508	116	0	0	0	26300	0
Podocarpus totara type	4340	277	1973	9181	1736	1220	3533	3246	4340	1645	1044	462	1085	404	34486	1
Prumnopitys	8990	1938	5918	3338	2170	3137	14467	9056	17926	1543	232	1385	217	270	70587	1
Pinus	11160	2214	3945	5842	1953	784	3869	1538	1698	411	1625	3001	7595	2157	47793	1
Phyllocladus	36580	3321	7891	4173	1302	959	6056	2307	4717	2365	3481	1385	217	270	75024	1
Cupressaceae	0	166	0	0	0	0	336	171	566	206	0	1385	217	0	3047	0
Aristotelia	1240	0	15782	6677	0	0	0	0	0	0	0	0	0	0	23699	0
Ascarina	1860	277	7891	4173	868	174	505	342	189	103	0	231	0	0	16612	0
Casuarina	0	55	0	0	0	0	168	85	0	0	348	0	0	0	657	0
Myrtaceae	0	0	0	0	0	0	0	85	377	0	0	0	0	0	463	0
Griselina	0	0	21700	5008	651	0	0	0	0	0	0	0	0	0	27359	0
Hoheria	0	0	3945	9181	8680	174	0	256	0	0	0	0	0	135	22372	0
Leycesteria	0	55	0	0	434	0	0	0	0	0	0	0	0	0	489	0
Metrosideros	20150	2657	1457845	479069	85932	1046	2019	940	1510	926	116	0	0	135	2052344	34
Muehlenbeckia	0	3598	96664	30046	11935	0	0	0	377	0	0	0	0	0	142620	2
Nothofagus fusca type	8370	388	23673	10850	4774	3922	12112	7604	47740	35687	29127	28856	44919	3370	261390	4
Nothofagus menziesii	0	0	0	0	0	0	168	0	566	103	0	0	0	0	837	0
Quintinia	7750	1827	187409	130200	7595	436	505	513	943	514	0	231	0	0	337922	6
Salix	0	0	0	0	0	174	168	0	0	0	116	0	0	0	459	0
Schefflera	0	443	9864	6677	1953	0	0	0	0	0	0	0	0	0	18936	0
Weinmannia	3720	332	197273	80958	25606	349	673	256	566	309	116	0	0	0	310157	5
Coprosma	2170	996	13809	50912	8029	3050	4542	3588	3774	1234	580	8541	2387	1887	105500	2
Discaria	0	0	0	0	0	0	0	0	0	0	0	2539	217	135	2891	0
Epacridaceae	0	55	3945	3338	2821	261	673	0	566	206	0	0	217	404	12488	0
Fuchsia	0	0	0	835	0	0	0	0	0	0	0	0	0	0	835	0
Leptospermum	930	55	0	0	0	0	0	0	0	411	0	923	0	0	2320	0
Myrsine	1550	2546	0	835	434	436	336	854	377	103	0	0	0	0	7472	0
Acaena	0	0	0	0	0	0	0	85	189	0	0	0	0	0	274	0
Apiaceae	1550	0	3945	16692	0	174	1178	683	189	0	348	5771	3472	674	34677	1
Asteraceae	1240	221	33536	5008	20398	2092	1346	1538	755	309	116	1616	2170	539	70883	1
Bulbinella	0	0	0	0	0	0	0	0	0	0	0	0	0	2157	2157	0
Centrolepidaceae	310	0	0	0	0	349	9252	256	3397	1954	0	0	0	0	15517	0
Chenopodiaceae	0	0	0	0	0	87	168	342	189	0	0	0	0	0	786	0
Coriaria	0	0	130200	220338	18445	174	1178	427	566	411	232	462	434	2830	375698	6
Crassulaceae	0	0	23673	20865	0	0	0	0	0	0	0	0	0	0	44538	1
Cyperaceae	620	166	0	0	217	26929	9420	4186	3208	4422	11836	33704	16709	13613	125031	2
Donatia	0	0	0	0	0	0	336	0	1321	0	0	0	0	0	1657	0
Drosera arcturi	0	0	0	0	0	87	0	0	0	0	0	0	0	0	87	0
Gentiana	0	0	1973	835	434	0	168	256	0	206	0	0	0	0	3872	0
Haloragis	0	0	0	0	0	0	0	0	0	0	348	1385	3255	0	4988	0
Lotus	0	55	1973	0	868	0	0	0	0	0	0	0	0	0	2896	0
Papilionaceae	0	0	11836	5008	1519	0	0	171	0	0	0	0	0	0	18534	0
Phormium	0	0	3945	4173	0	87	0	0	0	0	0	462	0	0	8667	0
Plantago (indigenous)	0	0	0	0	0	87	0	85	0	0	0	462	0	0	634	0
Plantago lanceolata	310	55	0	1669	868	0	0	0	189	0	0	0	1519	539	5149	0
Poaceae	127410	996	86800	307138	106330	10196	14130	8458	4151	6891	11372	174754	110453	42052	1011133	17
Ranunculus	0	0	3945	5008	0	174	841	598	0	0	0	0	0	270	10836	0
Rubus	0	0	1973	0	0	0	0	0	0	0	0	0	0	0	1973	0
Rumex	0	0	0	25038	2604	0	336	85	1132	206	0	1616	868	0	31886	1
Taraxacum	2790	166	47345	35054	47306	0	168	683	0	103	232	11543	1085	674	147149	2
Typha	0	0	0	0	0	0	0	0	0	0	0	19161	0	0	19161	0
Monolete	4960	3321	5918	7512	1302	610	3196	854	1698	823	580	3694	3906	21026	59401	1
Cyathea	7750	2270	3945	0	1953	697	1346	683	1510	926	464	0	217	0	21761	0
Dicksonia fibrosa	0	0	0	0	0	0	336	0	0	0	0	0	0	0	336	0
Dicksonia squarrosa	3410	664	5918	0	0	87	168	85	377	103	0	0	0	0	10814	0
Pteridium	0	55	0	0	0	0	0	0	0	0	348	462	217	0	1082	0
Lycopodium	0	0	0	0	0	784	0	427	3963	206	0	462	434	539	6815	0
Total pollen count	496000	38750	2434345	1502308	370853	61004	117752	59803	132087	71991	81230	307032	202678	94348	5970180	100
Exotic marker	70	392	11	26	100	249	129	254	115	211	187	94	100	161		

APPENDIX E

Absolute values with 95% confidence limits. Only major taxa shown.

Site / Taxa		B	C	H	I	J	K	L	M	N	Q	R	AF	AL	AP
	u	299564	11424	17836	10880	2651	2422	16195	3850	10130	2072	1723	4429		1060
Rimu	x	**233740**	**9521**	**3945**	**4173**	**1085**	**1482**	**12112**	**2648**	**6982**	**1131**	**812**	**2309**	--	**270**
	l	182379	7935	873	1601	445	906	9058	1822	4812	618	383	1203		69
	u	7712	665	14719	18670	3562	2090	5608	4572	6799	2736	2036	1829	2651	1250
Totara	x	**4340**	**277**	**1973**	**9180**	**1736**	**1220**	**3533**	**3246**	**4340**	**1645**	**1044**	**462**	**1085**	**404**
	l	2442	115	264	4515	846	712	2225	2305	2770	990	536	116	445	131
	u	13888	2741	21454	9556	4155	4456	19049	11387	23580	2605	911	3152	1451	1060
Miro	x	**8990**	**1938**	**5918**	**3338**	**2170**	**3137**	**14467**	**9056**	**17926**	**1543**	**232**	**1385**	**217**	**270**
	l	5819	1369	1633	1166	1134	2209	10987	7202	13628	914	59	609	33	69
	u	16720	3070	17836	13505	3860	1523	6036	2481	3343	1097	2796	5363	11181	3606
Pinus	x	**11160**	**2214**	**3945**	**5842**	**1953**	**784**	**3869**	**1538**	**1698**	**411**	**1625**	**3001**	**7595**	**2157**
	l	7449	1597	873	2527	988	404	2480	953	863	154	944	1680	5159	1290
	u	49306	4367	25151	10880	2958	1752	8777	3434	7280	3641	5125	3152	1451	1060
Phyllocladus	x	**36580**	**3321**	**7891**	**4173**	**1302**	**959**	**6056**	**2307**	**4717**	**2365**	**3481**	**1385**	**217**	**270**
	l	27138	2526	2479	1601	573	525	4178	1550	3057	1537	2365	609	33	69
	u	28316	3592	2696891	714217	107331	1865	3647	1717	3086	1801	771		1451	896
Rata	x	**20150**	**2657**	**1457845**	**479069**	**85932**	**1046**	**2019**	**940**	**1510**	**926**	**116**	--	**217**	**135**
	l	14339	1966	788059	321341	68799	586	1117	514	738	476	17		33	20
	u	13075	816	54688	21223	7584	5396	16195	9702	59684	42483	35303	37810	57189	5141
Beech	x	**8370**	**388**	**23673**	**10850**	**4774**	**3922**	**12112**	**7604**	**47740**	**35687**	**29127**	**28856**	**44919**	**3370**
	l	5358	184	10247	5547	3005	2850	9058	5959	38186	29978	24031	22023	35282	2209
	u	12260	2609	356840	198449	11181	1050	1565	1147	2298	1241		1545		
Quintinia	x	**7750**	**1827**	**187409**	**130200**	**7595**	**436**	**505**	**513**	**943**	**514**	--	**230**	--	--
	l	4899	1279	98425	85422	5159	181	163	229	387	213		35		
	u	6868	741	375014	125587	33509	928	1806	789	1758	951	771			
Weinmannia	x	**3720**	**332**	**197273**	**80958**	**25606**	**349**	**673**	**256**	**566**	**309**	**116**	--	--	--
	l	2015	149	103773	52188	19567	131	251	83	182	100	17			
	u	4713	1599	36273	81068	11729	4351	6886	4981	6074	2207	1402	12519	4449	3258
Coprosma	x	**2170**	**996**	**13809**	**50912**	**8030**	**3050**	**4542**	**3588**	**3774**	**1234**	**580**	**8541**	**2387**	**1887**
	l	999	621	5257	31973	5492	2138	2996	2585	2345	690	240	5828	1281	1093
	u	3825		17836	30071		683	2513	1378	1259		1075	8985	5891	1632
Apiaceae	x	**1550**	--	**3945**	**16692**	--	**174**	**1178**	**683**	**189**	--	**348**	**5772**	**3472**	**674**
	l	628		873	9266		44	552	339	28		113	3708	2047	278
	u	3374	588	73004	12197	27099	3183	2744	2481	2030	951	771	3475	4155	1442
Asteraceae	x	**1240**	**221**	**33536**	**5008**	**20398**	**2092**	**1346**	**1538**	**755**	**309**	**116**	**1616**	**2170**	**539**
	l	456	83	15406	2056	15354	1375	660	953	281	100	17	752	1134	202
	u			251419	331739	24689	683	2513	1029	1758	1097	911	1829	1717	4464
Coriaria	x	--	--	**130200**	**220338**	**18445**	**174**	**1178**	**427**	**566**	**411**	**232**	**462**	**434**	**2830**
	l			67425	146347	13780	44	552	177	182	154	59	116	110	1795
	u	2470	510			1451	31924	12917	5693	5342	6149	15102	43795	22544	17500
Cyperaceae	x	**620**	**166**	--	--	**217**	**26929**	**9420**	**4186**	**3208**	**4422**	**11836**	**33705**	**16709**	**13613**
	l	156	54			33	22715	6870	3078	1926	3181	9277	25938	12384	10590
	u	164678	1599	171404	460062	132246	12733	18642	10694	6558	9089	14555	217205	137282	51015
Poaceae	x	**127410**	**996**	**86800**	**307138**	**106330**	**10196**	**14130**	**8458**	**4151**	**6891**	**11372**	**174754**	**110453**	**42052**
	l	98576	621	43956	205046	85493	8165	10711	6689	2628	5224	8885	146000	88867	34664
	u	5584	510	98565	57515	60110		1121	1378		683	911	16302	2651	1632
Taraxacum	x	**2790**	**166**	**47345**	**35054**	**47306**	--	**168**	**683**	--	**103**	**232**	**11542**	**1085**	**674**
	l	1394	54	22742	21365	37229		25	339		15	59	8173	445	278
	u	632185	44035	4495458	2054142	455166	70758	142531	69294	161388	84268	95780	379672	249883	112350
Total	x	**496000**	**38750**	**2434345**	**1502308**	**370853**	**61004**	**117752**	**59803**	**132087**	**71991**	**81230**	**307032**	**202678**	**94348**
	l	389152	34099	1318229	664659	302157	52595	97281	51612	108106	61502	68890	248289	164390	79230

u = upper limit; x = mean; l = lower limit

APPENDIX F

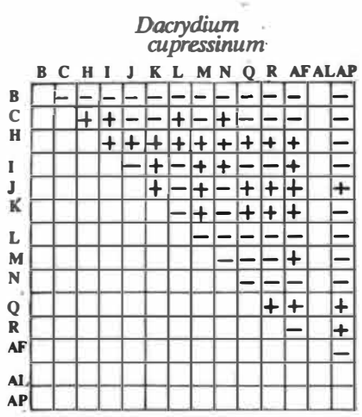
Pollen percent data from the 'absolute' values.

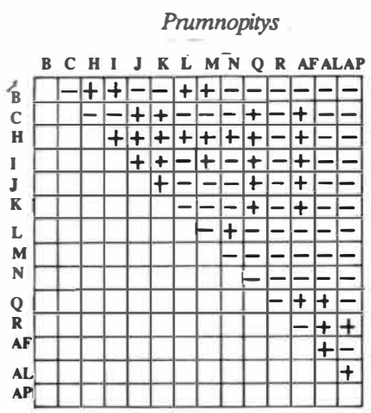
	B	C	H	I	J	K	L	M	N	Q	R	AF	AL	AP
Dacrycarpus dacrydioides	+	-	+	+	+	+	1	1	1	+	-	+	+	-
Dacrydium cupressinum	47	25	+	+	+	2	10	4	5	2	1	1	-	+
Halocarpus type	+	+	-	+	+	+	5	1	4	1	22	-	+	-
Lagarostrobos colensoi	+	-	-	-	+	+	+	1	-	-	-	-	-	
Lepidothamnus	-	-	-	-	-	1	3	9	7	10	+	-	-	-
Podocarpus totara type	1	1	+	1	+	2	3	5	3	2	1	+	1	+
Prumnopitys	2	5	+	+	1	5	12	15	14	2	+	+	+	+
Pinus	2	6	+	+	1	1	3	3	1	1	2	1	4	2
Phyllocladus	7	9	+	+	+	2	5	4	4	3	4	+	+	+
Cupressaceae	-	+	-	-	-	-	+	+	+	+	-	+	+	-
Aristotelia	+	-	1	+	-	-	-	-	-	-	-	-	-	-
Ascarina	+	1	+	+	+	+	+	1	+	+	-	+	-	-
Griselina	-	-	1	+	+	-	-	-	-	-	-	-	-	-
Hoheria	-	-	+	1	2	+	-	+	-	-	-	-	-	+
Metrosideros	4	7	61	32	23	2	2	2	1	1	+	-	-	+
Muehlenbeckia	-	9	4	2	3	-	-	-	+	-	-	-	-	-
Nothofagus fusca type	2	1	1	1	1	6	10	13	37	50	36	9	22	4
Quintinia	2	5	8	9	2	1	+	1	1	1	+	+	+	+
Schefflera	-	1	+	+	1	-	-	-	-	-	-	-	-	-
Weinmannia	1	1	8	5	7	1	1	+	+	+	+	-	-	-
Coprosma	+	3	1	3	2	5	4	6	3	2	1	3	1	2
Discaria	-	-	-	-	-	-	-	-	-	-	-	1	+	+
Epacridaceae	-	+	+	+	1	+	1	-	+	+	-	-	+	+
Leptospermum	+	+	-	-	-	-	-	-	-	1	-	+	-	-
Myrsine	+	7	-	+	+	1	+	1	+	+	-	-	-	-
Apiaceae	+	-	+	1	-	+	1	1	+	-	+	2	2	1
Asteraceae	+	1	1	+	6	3	1	3	1	+	+	1	1	1
Bulbinella	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Centrolepidaceae	+	-	-	-	-	1	8	+	3	3	-	-	-	-
Chenopodiaceae	-	-	-	-	-	+	+	1	+	-	-	-	-	-
Coriaria	-	-	5	15	5	+	1	1	+	1	+	+	+	3
Cyperaceae	+	+	-	-	+	44	8	7	2	6	15	11	8	14
Haloragis	-	-	-	-	-	-	-	-	-	-	+	+	2	-
Plantago	+	+	-	+	+	-	-	-	+	-	-	+	1	1
Poaceae	26	3	4	21	29	17	12	14	3	10	14	57	55	45
Ranunculus	-	-	+	+	-	+	1	1	-	-	-	-	-	+
Rumex	-	-	-	2	1	-	+	+	1	+	-	1	+	-
Taraxacum	1	+	2	2	13	-	+	1	-	+	+	4	1	1
Typha	-	-	-	-	-	-	-	-	-	-	-	6	-	-
Monolete	1	9	+	1	+	1	3	1	1	1	1	1	2	22
Cyathea	2	6	+	-	1	1	1	1	1	1	1	-	+	-
Dicksonia	1	2	+	-	-	+	+	+	+	+	-	-	-	-
Lycopodium	-	-	-	-	-	1	-	1	3	+	-	+	+	1

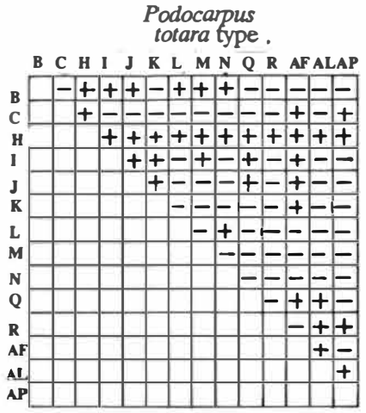
+ = less than 1%

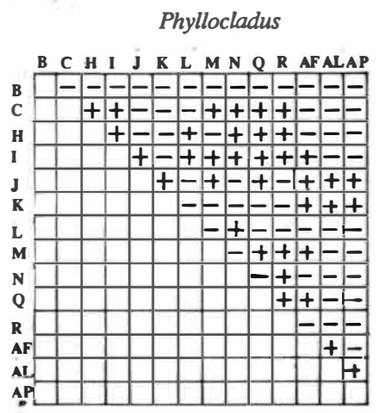
- = not observed

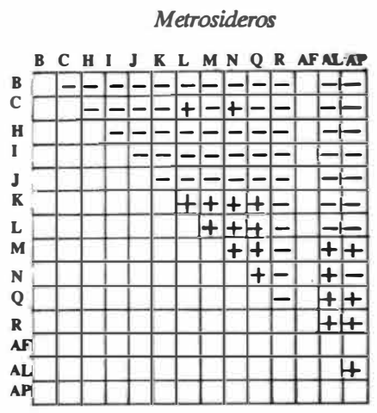
Appendix G. Results of the null hypothesis for the concentration study (Table 4.1).

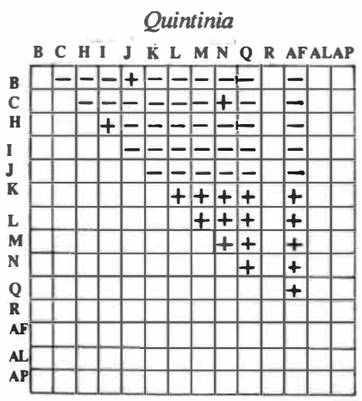


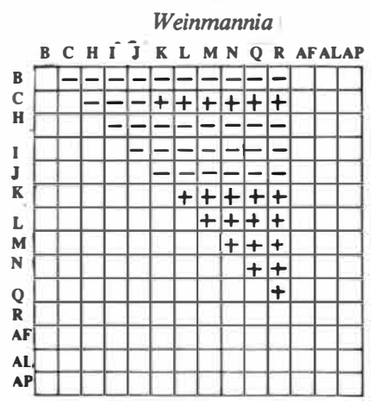


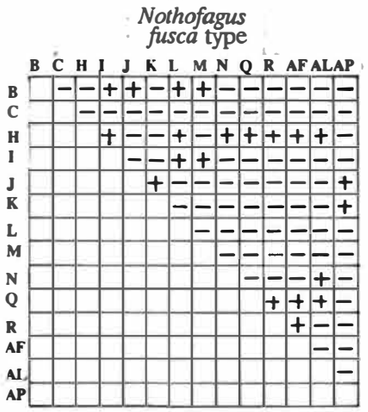


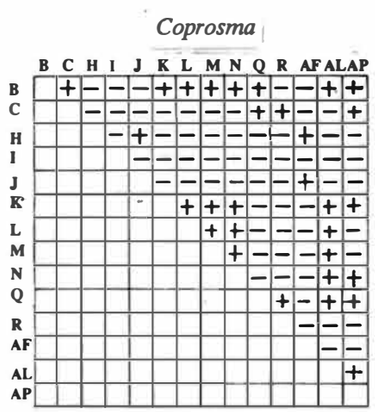


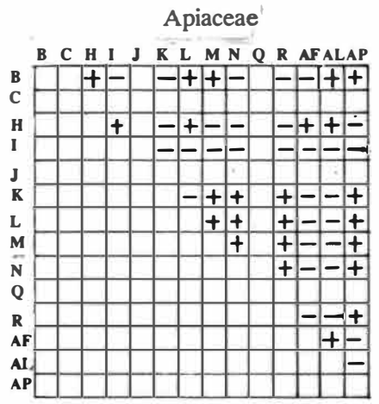


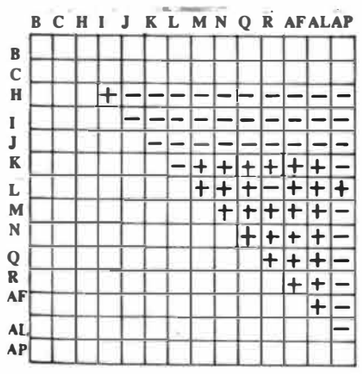


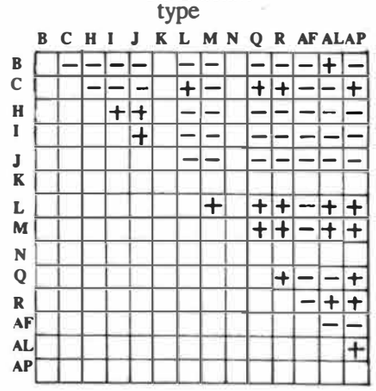












The null hypothesis (that the differences between the two concentrations result simply from chance variability expected in samples with the same pollen concentration) (Maher 1981).

\+ = Accept null hypothesis (values are the same).

\- = Reject null hypothesis (values are different).

Only major taxa shown.

APPENDIX H

Main Divide monolith, raw counts.

Depth (cm)	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	30-32	32-34	34-36	36-38	38-40	40-42	Total	Total
Taxa																						sum	%
Dacrydium cupressinum	40	51	31	47	46	60	39	48	46	26	59	82	73	54	37	60	57	67	62	47	40	1072	7
Dacrycarpus dacrydioides	5	14	7	5	7	5	7	6	9	6	15	11	12	12	7	15	8	4	7	11	13	186	1
Halocarpus type	3	5	5	6	7	14	9	11	9	3	7	3	6	3	7	3	3	1	4	5	2	116	1
Lagarostrobos colensoi	1	1	1	-	2	4	1	2	1	-	-	1	2	1	2	2	3	1	2	4	1	32	0
Lepidothamnus	7	11	11	7	13	20	5	11	5	3	12	13	12	12	15	8	13	8	11	11	7	215	1
Podocarpus totara type	20	14	15	24	32	22	14	27	19	20	25	35	27	27	27	44	35	26	27	27	23	530	4
Prumnopitys	28	40	18	29	47	45	30	46	39	33	43	33	41	21	23	38	27	29	44	40	21	715	5
Pinus	9	10	5	15	5	4	5	8	3	1	4	1	2	-	-	-	-	-	-	-	-	72	0
Phyllocladus	14	11	26	28	13	23	20	18	15	16	17	23	27	25	32	31	24	32	24	19	27	465	3
Cupressaceae	2	4	4	5	3	3	1	2	1	1	4	3	4	6	6	4	4	6	5	2	3	73	0
Ascarina	2	-	-	2	2	-	1	-	2	2	1	1	1	-	2	-	-	1	-	1	-	18	0
Casuarina	1	-	1	1	2	2	-	-	-	1	-	1	-	-	-	-	-	3	1	1	1	15	0
Hoheria	-	-	-	1	-	-	3	2	-	-	-	1	-	-	1	1	-	-	-	-	2	11	0
Myrtaceae	-	-	-	-	2	1	-	-	2	-	-	-	-	1	-	-	-	3	1	-	-	10	0
Metrosideros	4	11	5	4	6	6	10	5	3	6	7	9	9	9	11	7	13	11	11	14	6	167	1
Nothofagus fusca type	41	61	52	73	54	88	84	92	80	89	81	87	82	72	92	105	90	97	94	101	77	1692	12
Nothofagus menziesii	-	1	2	1	1	3	2	1	1	1	1	1	2	3	5	6	1	3	-	7	3	45	0
Quintinia	7	8	10	4	3	8	5	5	8	8	5	13	12	12	7	10	13	16	11	13	5	183	1
Salix	-	-	-	1	-	-	1	1	-	-	1	1	-	-	-	-	-	-	-	-	-	5	0
Weinmannia	1	3	6	2	3	2	3	3	3	6	1	7	4	4	6	1	3	5	2	3	3	71	0
Coprosma	29	30	31	33	19	31	16	18	16	20	26	18	23	22	22	15	16	10	19	18	18	450	3
Epacridaceae	1	15	2	7	4	4	6	-	1	2	4	2	4	1	6	3	2	3	1	1	1	70	0
Myrsine	1	2	2	4	1	2	5	-	3	5	2	1	5	7	3	4	5	3	1	1	7	64	0
Acaena	-	-	-	1	-	2	-	2	-	2	-	1	3	3	3	-	-	-	-	-	-	17	0
Apiaceae	2	9	4	9	9	8	5	3	5	6	8	6	6	11	12	12	14	8	6	12	8	163	1
Asteraceae	1	8	5	13	4	8	13	5	11	2	11	8	9	7	10	7	2	11	8	5	5	153	1
Centrolepidaceae	55	39	28	48	47	56	45	46	44	51	58	52	75	84	64	84	94	107	135	100	67	1379	9
Chenopodiaceae	-	2	1	-	2	1	4	1	3	1	1	1	1	-	-	1	1	-	-	-	-	20	0
Coriaria	1	3	1	4	-	2	7	4	7	2	9	8	4	6	8	4	3	8	10	8	5	104	1
Cyperaceae	274	204	257	187	212	153	213	184	229	218	160	159	150	182	212	147	180	180	169	200	290	4160	28
Donatia	1	4	4	5	5	5	10	16	11	13	21	14	12	12	5	6	-	-	-	-	-	144	1
Drosera arcturi	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	1	1	0
Epiliobium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	0
Gentiana	-	3	-	-	3	1	1	4	-	-	1	-	3	1	1	1	-	-	-	1	1	21	0
Gunnera	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1	0
Haloragis	-	-	1	-	-	-	-	-	-	-	2	-	-	-	1	1	-	1	-	-	-	6	0
Phormium	-	-	-	1	-	-	1	-	-	1	-	-	1	-	-	-	-	-	1	-	-	5	0
Plantago (indigenous)	-	-	-	-	1	4	-	-	1	4	1	3	1	2	2	2	-	2	1	-	1	25	0
Plantago lanceolata	1	1	2	-	-	-	1	-	-	-	2	-	2	-	-	-	-	-	-	-	-	9	0
Poaceae	109	106	119	91	93	66	96	81	89	110	64	53	54	59	43	32	39	28	25	30	40	1427	10
Ranunculus	1	-	-	-	-	-	1	1	2	-	-	1	1	2	-	-	-	1	1	1	-	12	0
Rumex	9	4	1	9	4	2	3	6	2	3	10	6	3	2	8	2	6	5	4	3	5	97	1
Taraxacum	1	1	2	-	-	-	-	-	1	-	-	-	-	-	-	1	1	-	-	-	-	7	0
Unidentified	5	1	1	4	4	4	1	3	1	6	1	6	2	2	2	5	12	5	3	3	4	75	1
Cyathea	9	9	14	6	7	12	1	4	6	6	7	3	4	8	3	6	6	5	1	-	3	120	1
Dicksonia squarrosa	-	1	3	1	4	5	1	2	2	-	-	-	1	2	-	2	2	-	-	-	-	26	0
Monolete	10	11	22	17	27	16	24	26	18	23	19	19	15	19	13	26	19	7	9	6	9	355	2
Trilete	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	2	0
Lycopodium	5	2	1	5	6	8	6	6	2	3	10	13	4	6	2	3	2	3	-	5	1	93	1
Total pollen count	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	14700	100

APPENDIX I

Bealey River, raw pollen counts

depth (cm)	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	30-32	32-34	34-36	36-38	38-40	40-42	Total	Total
TAXON																						sum	%
Dacrydium cupressinum	39	26	17	40	43	44	60	59	56	37	51	40	45	60	51	49	51	39	48	51	54	960	7
Dacrycarpus dacrydioides	2	5	2	1	6	2	6	2	3	5	7	2	5	6	1	6	5	2	2	-	1	71	0
Halocarpus type	20	14	13	31	41	35	44	46	34	31	29	24	21	41	25	25	29	30	26	24	20	603	4
Lagarostrobos colensoi	-	1	-	-	2	5	4	5	1	3	4	4	3	-	1	2	2	1	2	-	2	42	0
Lepidothamnus	8	11	7	15	23	41	37	41	38	38	37	31	39	53	49	63	39	30	19	19	14	652	4
Podocarpus totara type	8	14	9	16	13	21	17	22	19	24	22	21	19	13	15	18	15	19	16	7	10	338	2
Prumnopitys	22	18	22	48	32	31	64	65	64	59	69	60	58	70	72	70	82	74	59	39	55	1133	8
Pinus	5	2	1	2	8	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19	0
Podocarpaceae	-	-	2	-	-	7	3	4	5	1	2	1	4	2	-	-	-	-	-	-	2	33	0
Phyllocladus	17	17	13	12	19	23	23	18	17	22	16	29	23	21	19	20	21	23	28	24	30	435	3
Cupressaceae	4	2	1	-	1	7	4	3	6	5	4	5	-	7	3	2	3	3	4	3	4	71	0
Ascarina	1	1	2	2	2	2	1	3	2	1	-	-	-	1	1	2	1	1	-	3	1	27	0
Casuarina	-	-	-	-	1	1	1	-	-	-	1	1	1	-	-	2	-	1	1	-	-	10	0
Hoheria	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	2	-	-	1	-	5	0
Myrtaceae	-	3	-	1	1	-	1	2	3	1	-	1	-	-	-	1	-	1	1	1	-	17	0
Metrosideros	2	3	3	5	3	8	5	7	9	6	13	9	3	7	5	11	9	13	5	7	1	134	1
Nothofagus fusca type	277	343	282	301	319	323	274	269	291	304	314	290	329	281	320	291	314	309	319	355	340	6445	44
Nothofagus menziesii	1	1	2	3	2	3	1	4	6	4	3	5	4	2	5	6	6	4	3	4	4	73	0
Pseudowintera	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0
Quintinia	3	5	4	5	8	11	4	5	2	6	2	3	4	4	3	2	7	2	3	6	1	90	1
Weinmannia	1	1	-	2	3	2	2	1	2	1	2	3	1	5	2	-	-	2	-	-	2	32	0
Coprosma	12	16	15	15	12	10	16	17	8	10	13	10	13	7	16	4	5	12	22	18	13	264	2
Epacridaceae	2	7	4	4	1	2	3	4	2	2	4	5	6	2	3	3	1	1	2	2	7	67	0
Myrsine	3	3	4	-	4	-	-	-	1	4	-	1	3	1	1	1	3	3	7	3	2	44	0
Acaena	-	-	-	-	1	-	-	-	1	-	-	-	-	-	1	-	1	-	1	-	-	5	0
Apiaceae	5	1	3	6	2	2	5	2	3	7	5	7	3	3	2	1	1	6	3	-	-	67	0
Asteraceae	2	3	4	1	2	5	5	3	3	7	5	7	5	7	2	2	4	3	5	4	2	81	1
Centrolepidaceae	198	93	190	80	40	9	19	18	13	22	25	23	26	21	24	36	39	46	63	79	65	1129	8
Chenopodiaceae	1	4	-	2	2	-	-	2	-	2	2	1	-	2	1	1	1	-	-	-	-	21	0
Coriaria	-	4	3	1	4	4	5	4	3	2	4	3	4	1	-	1	-	1	-	1	1	46	0
Cyperaceae	18	12	20	41	35	36	32	51	58	44	26	62	38	41	37	30	20	36	29	23	36	725	5
Donatia	4	24	11	7	5	9	8	5	3	8	7	-	14	3	5	7	-	-	-	-	-	120	1
Drosera arcturi	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	3	0
Gentiana	-	-	-	-	2	3	1	-	2	-	-	-	-	2	1	1	1	1	2	1	3	20	0
Gunnera	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0
Haloragis	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	2	-	-	-	-	-	4	0
Plantago (indigenous)	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	0
Plantago lanceolata	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	0
Poaceae	12	25	26	22	36	22	23	18	15	24	14	25	8	12	10	7	11	8	5	3	10	336	2
Ranunculus	-	-	-	-	2	-	1	-	-	1	1	-	-	1	-	1	-	-	-	-	-	7	0
Rumex	4	2	2	4	2	5	-	1	7	2	5	2	1	2	4	2	-	4	3	2	-	54	0
Taraxacum	1	1	1	3	5	7	2	2	1	2	-	-	-	-	-	-	-	-	-	-	-	25	0
Unidentified	16	12	18	15	2	7	14	4	9	3	3	9	4	6	5	8	11	4	5	9	12	176	1
Cyathea	2	4	10	5	1	1	2	4	-	2	3	4	2	4	5	6	5	9	6	-	-	75	1
Dicksonia squarrosa	-	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	4	0
Monolete	6	15	8	6	15	6	12	9	12	9	5	12	12	12	10	16	10	11	9	5	6	207	1
Trilete	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	4	-	5	0
Lycopodium	3	2	-	3	-	2	-	-	1	-	-	-	1	-	1	1	-	-	2	2	2	20	0
Total pollen count	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	14700	100

APPENDIX J

Cave Stream raw counts

Depth (cm)	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	30-32	32-34	34-36	36-38	Total	Total
Taxa																				sum	%
Podocarpaceae (total)	7	8	3	6	5	4	7	6	10	6	11	21	21	34	16	23	21	16	21	246	2
Dacrydium cupressinum	1	1	2	3	2	1	4	1	4	1	7	9	10	14	8	11	11	9	15	114	1
Dacrycarpus dacrydioides	-	-	1	-	-	-	-	-	-	-	-	3	1	3	-	2	1	-	-	11	0
Halocarpus type	-	-	-	-	-	-	-	-	1	1	1	3	5	6	3	8	15	31	15	89	1
Podocarpus totara type	2	4	-	2	1	2	3	4	1	2	4	4	3	7	4	2	1	-	2	48	0
Prumnopitys	4	3	-	1	2	1	-	1	5	3	-	5	7	10	4	8	8	7	4	73	1
Pinus	19	7	5	5	8	14	1	4	3	1	3	-	1	-	-	-	-	-	-	71	1
Phyllocladus	2	3	3	2	1	3	3	2	2	4	3	4	7	6	6	6	10	4	8	79	1
Ascarina	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0
Betula	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	2	0
Myrtaceae	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	4	0
Metrosideros	1	-	-	3	2	-	-	-	1	-	-	-	-	2	2	3	-	-	-	14	0
Nothofagus fusca type	177	92	127	103	124	139	125	133	159	137	132	171	256	223	229	222	243	244	259	3295	25
Nothofagus menziesii	1	-	-	-	-	-	-	-	-	-	1	-	-	-	1	1	2	2	2	10	0
Quintinia	-	-	-	-	1	-	1	1	1	1	-	1	1	-	-	-	1	2	2	12	0
Salix	1	1	-	4	1	-	1	1	1	-	-	-	-	-	-	-	-	-	-	10	0
Coprosma	9	3	7	6	2	3	3	6	2	1	4	20	20	19	18	30	32	40	21	246	2
Discaria	5	-	-	-	-	6	2	-	2	-	-	-	-	1	-	-	-	-	-	16	0
Epacridaceae	-	-	2	1	-	-	2	-	-	-	-	5	6	4	3	4	1	-	1	29	0
Leptospermum	-	-	-	1	-	1	1	-	-	1	1	-	-	1	1	1	-	-	-	8	0
Myrsine	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	2	4	0
Pimelea	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	2	-	-	3	0
Acaena	-	-	1	1	-	-	2	1	2	2	-	10	2	12	1	-	-	-	1	35	0
Apiaceae	52	107	95	115	88	74	99	117	85	67	196	52	82	65	63	84	77	72	71	1661	12
Asteraceae	2	23	21	37	31	44	60	61	50	46	26	6	13	12	10	19	23	38	28	550	4
Chenopodiaceae	1	-	-	1	1	-	-	-	-	1	-	-	-	-	1	-	-	1	-	6	0
Coriaria	2	-	-	-	1	-	-	-	-	-	1	-	2	1	-	-	1	-	-	8	0
Cyperaceae	13	115	77	87	168	137	152	142	145	153	115	254	174	177	218	174	162	136	145	2744	21
Epilobium		-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	0
Galium		-	-	-	-	-	-	-	2	-	-	-	-	1	-	-	-	-	-	3	0
Gentiana		-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	0
Haloragis		3	3	-	-	1	2	-	1	1	2	1	-	-	-	-	-	-	-	14	0
Hebe		-	-	-	-	-	-	-	-	-	-	-	2	3	6	3	8	1	1	3	27	0
Plantago (indigenous)		-	1	-	-	-	-	-	2	-	2	-	-	1	1	-	1	1	-	-	9	0
Plantago lanceolata		-	1	-	-	-	1	-	-	1	3	-	-	-	-	-	-	-	-	-	6	0
Poaceae	3	93	323	331	297	244	249	215	190	192	238	162	105	83	111	98	88	77	87	87	3570	27
Ranunculus		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	3	0
Rumex		7	4	15	12	11	8	8	9	14	13	28	27	4	-	-	-	-	-	-	160	1
Taraxacum		-	8	3	7	5	7	13	16	15	17	8	2	-	2	2	1	6	1	8	121	1
Typha		-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	1	3	0
Wahlenbergia		-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	2	0
Unidentified		-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	2	0
Cyathea		1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	2	0
Monolete		2	1	10	11	6	5	4	7	10	4	7	17	19	12	23	26	20	20	23	227	2
Lycopodium		-	-	-	-	-	2	1	-	-	-	-	-	-	-	1	1	-	1	-	6	0
Total pollen count		700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	13300	100

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